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NASTAVAK RUDARSKIH AKTIVNOSTI RTB-a BOR NA LOKALITETU KRAKU BUGARESKU CEMENTACIJA SA ANALIZOM OSETLJIVOSTI IRR IZBORA VARIJANTI OTKOPAVANJA[***]

Izvod

Radom su opisane aktivnosti na nastavku eksploatacije na lokalitetu Kraku bugaresku Cementacija 1 i 2, sa kratkim prikazom istorijata dosadašnjih izvedenih i sadašnjim stanjem rudarskih radova, kao i koncepcijom buduće eksploatacije.

Zbog planiranih izmena u koncepciji buduće eksploatacije sa aspekta prelaska na veći kapacitet (5,5 Mt godišnje) u odnosu na projektovani od 2,5 Mt kao i smanjenja broja faza (push backs) u razvoju kopa Cementacija 2 u odnosu na projektovano rešenje od strane Investitora, prikazana je i analiza osetljivosti Interne stope rentabilnosti (IRR) na promenu flotacijskog iskorišćenja, kao implicitne posledice smanjenja broja aktivnih radilišta na rudi u istovremenom radu. Drugim rečima – eksploatacija sa manjim brojem faza u otkopavanju smanjuje mogućnost blendinga prema flotaciji čime utiče na koherentnost sadržaja metala u rudi koja se dozira flotaciji, odnosno iskorišćenje u flotaciji. Smanjenjem iskorišćenja, smanjuje se i prihod, a time se utiče i na IRR kao jednan od pokazatelja ekonomske ocene projekta .

***Ključne reči**: eksploatacija, stanje rudarskih radova, push backs, flotacijsko iskorišćenje, interna stopa rentabilnosti, investiciona ulaganja, povraćaj ulaganja.*

1. UVOD

Ležište rude bakra Kraku bugaresku - Cerovo nalazi se u Istočnoj Srbiji, oko 20 km severno od Bora (sl.1.).

Na ovom kompleksu rudnih ležišta (Cerovo Cementacija 1, Cerovo 2, Cerovo 3, Cerovo 4, Cerovo primarno i Drenova) eksploatacija je započeta kopom Cerovo Cementacija 1 koji je otvoren 1993. godine, a radovi na investicionom raskri-vanju započeli su još 1990. godine. Tokom investicionog raskri-vanja koje je trajalo od 1990. do 1993. godine, koliko je zapravo trajala izgradnja objekata prerade na lokaciji Cerova i hidrotransportnog sistema transpor-

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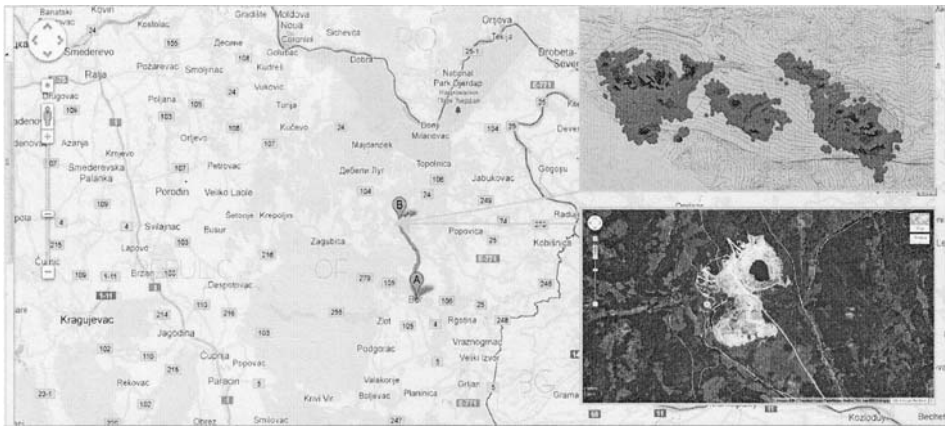
tovanja pulpe do borske flotacije, bilo je raskriveno oko 10 miliona tona jalovine (skoro polovina od ukupne količine u zahvatu kopa), čime su stvoreni uslovi za vrlo povoljnu kasniju eksploataciju sa malim koeficijentom raskrivke. To je svakako imalo svoju cenu, ali okolnosti su bile takve da je to je zapravo i omogućilo da se na ovom rudniku odvija eksploatacija i u vrlo teškim, skoro nemogućim uslovima, pri vrlo nepovoljnim tržišnim uslovima kada je cena bakra u jednom momentu (2002.) iznosila čak neverovatnih 1300 US$ po toni katodnog bakra.

Glavnim rudarskim projektom otkopavanja ležišta "Cerovo Cementacija" [1], definisane su sledeće eksploatacione reserve u konturi 0,3 % Cu kopa Cerovo Cementacija 1:

- Ruda ----------17.479.165 t
- Jalovina----------23.674.605 t
- Iskopine ----------41.153.770 t
- Srednji sadržaj Cu u rudi ----------0,713 % Cu,
- Srednji koeficijent raskrivke ----------1,35 t/t.



Sl. 1. *Položaj rudnog ležišta bakra "KB-Cementacija"RTB Bor (Google map)*

2. DOSADAŠNJE AKTIVNOSTI NA EKSPLOATACIJI RUDNOG LEŽIŠTA KRAKU BUGARESKU - CEROVO

Koncepcija eksploatacije se sastojala u klasičnom otkopavanju bušačko minerskim radovima sa diskontinuiranim – kamionskim transportom rude i raskrivke. Projektovana visina etaže bila je 15 m, putevi spiralni sa početkom na severozapadnoj strani kopa, sa kote 515, na lokaciji gde kop prelazi iz brdskog u dubinski tip. Širina puteva 20 m, sa nagibom do 10%.

Ruda je transportovana do primarnog drobljenja nakon čega je deponovana na zatvoreno skladište. Sledeća tehnološka faza je sekundarno i tercijalno drobljenje. Izdrobljena ruda je odatle je dozirana u sledeću fazu prerade - dva stadijuma mlevenja, sa šipkama i kuglama. Proces flotacijske prerade je na Cerovu išao do dobijanja pulpe koja se nakon zgušnjavanja, hidrauličnim putem transpor-

tovala do flotacije Bor gde je vršeno flotiranje. Odlaganje flotacijske jalovine je bilo na flotacijskom jalovištu RTH u Boru.

Problem vezan za dinamiku zamene opreme i kvalitet samog elektromašinskog održavanja zbog nedostatka rezervnih delova, koji je u rudarstvu nastao tokom devedesetih godina, a zbog poznatih limitiranih uslova privređivanja, kulminirao je tokom 2003/2004. godine, kada je *kop* prestao sa radom. Namera je bila da se izvrši konzerviranje preostale opreme i instalacija i to je u nekoj meri i učinjeno. Ostatak rudarske mehanizacije sa Cerova je vraćen u Veliki Krivelj kako bi se tamo održala kakva - takva proizvodnja.

Rudarski radovi na kopu Cerovo Cementacija 1 zaustavljeni na k +395 m (etaža 395), sa neznatnim otkopavanjem i na etaži 380. Odvodnjavanje kopa je nastavljeno još izvesno vreme, da bi se i sa tim prestalo. U sadašnjem trenutku, dno kopa je pod vodom (sl. 1), i tehničkim projektom odvodnjavanja biće definisani uslovi i način ispumpavanja akumuliranih količina vode sa dna kopa, sa ciljem stvaranja uslova za nastavak proizvodnje.

Tokom 2011/12. godine krenulo se sa revitalizacijom i nastavkom proizvodnje, ali sa nešto izmenjenom koncepcijom u odnosu na ranije definisanu, kako sa aspekta godišnjeg kapaciteta otkopavanja i prerade rude, tako i sa aspekta koncepta otkopavanja Cerova 2, odnosno celokupne dinamike.

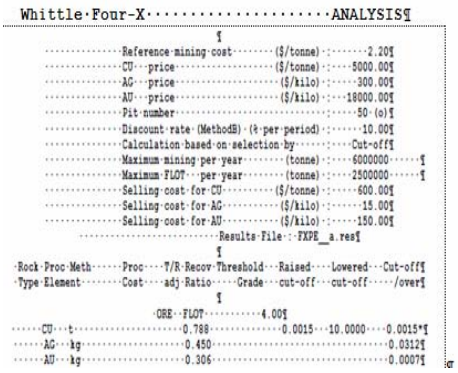
3. KONCEPCIJA PONOVNOG POKRETANJA RUDNIKA

Zbog toga što su se poslednjih godina uslovi na tržištu bakra poboljšali tako da je cena bakra u jednom momentu dostigla i cifru od 9 000 US$, čak i relativno siromašna ležišta su postala atraktivna i ekonomski isplativa za eksploataciju.

Strategija ponovnog aktiviranja eksploatacije rude bakra na lokaciji Cerovo – Kraku Bugaresku projektovana je *Dopunskim rudarskim projektom otkopavanja 2008. godine*, [2] i sastoji se u proširenju i produbljenju površinskog kopa Cerovo Cementacija 1, i otvaranju i eksploataciji rudnog ležišta Cementacija 2.

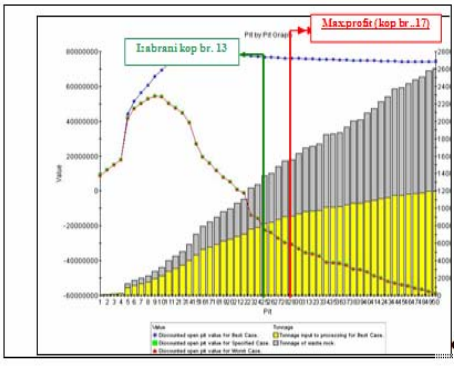
Optimizacijom je izvršen izbor kontura kopova, takođe i optimalne dugoročne dinamike otkopavanja po kriterijumu profita i diskontovanog profita za budući period eksploatacije, softverom Whittle Fx.

U tehničkom projektu otkopavanja (DRP 2008.) je detaljno obrađen navedeni postupak, s tim što je kapacitet rudnika bio ograničen (po zahtevu investitora) postojećim kapacitetom flotacijske prerade od 2,5 x 10^6 t rude.


Whittle Four-X ANALYSIS

Reference mining cost ($/tonne) 2.20
CU price ($/tonne) 5000.00
AG price ($/kilo) 300.00
AU price ($/kilo) 18000.00
Pit number 50 (o)
Discount rate (MethodB) (% per period) 10.00
Calculation based on selection by Cut-off
Maximum mining per year (tonne) 6000000
Maximum FLOT per year (tonne) 2500000
Selling cost for CU ($/tonne) 600.00
Selling cost for AG ($/kilo) 15.00
Selling cost for AU ($/kilo) 150.00
Results File : FXPE_a.res

Rock Type	Proc Meth Element	Proc Cost	T/R adj	Recov Ratio	Threshold Grade	Raised cut-off	Lowered cut-off	Cut-off /over
				ORE	FLOT 4.00			
	CU	t		0.788		0.0015	10.0000	0.0015*t
	AG	kg		0.450				0.0312t
	AU	kg		0.306				0.0007t



Grafik 1. *Ulazni parametri optimizacije i grafik sa prikazom profita i diskontovanog profita, i mogućim konturama kopa (50) za različite cene Cu*

Polazni parametri korišćeni u optimizaciji i grafik optimizacije u Whittle Fx:

Sa grafika 1 se vidi da krive profita i diskontovanog profita jako divergiraju sa povećanjem kapaciteta proizvodnje, što upućuje na fazno otkopavanje – push backs.

Spisak planirane opreme u rudarskom delu za kapacitet od 2,5Mt prikazan je u tabeli 1:

Tabela 1. *Planirana oprema DRP-om otkopavanja kompleksa rudnih tela Cerovo Kraku bugaresku*

No.	Naziv opreme	Karakteristike	Tip i oznaka	Kom.
1	Bušilica prečnika 250 mm	Rb=250 mm	Atlas Copco	1
2	Bušilica prečnika 89 - 130 mm	R89 do 130 mm	Atlas Copco	1
3	Hidraulični bager sa elektro pogonom	V_K= 10 m^3	Terex -OK	1
4	Utovarivač L-950	V_K=13 m^3	Leturnoau	1
5	Kamion-damper	nosivosti 90 Mt	HD785-7Komatsu	6
6	Bulldozer guseničar	CAT 249 KW)	CAT	2
7	Grjder	249 KW	CAT 16H	1
8	Cisterna za vodu FAP1823	V=9 m^3		1
9	Servisno vozilo FAP1318/42	Nosivost 8 t		2
10	Servisno terensko vozilo		Lada Niva	2
11	Muljne potapajuće pumpe	Flyght	BS 25.00	4
12	Utovarivač točkaš	V = 2.5 – 3		1

Koncepcija budućeg rada jeste da se u *prvoj godini* pokretanja proizvodnje na kompleksu, sa radovima raskrivanja započne na kopu Cementacija 1, odnosno postojećem kopu. U prvoj godini treba raskrivanjem stvoriti uslove da se pun kapacitet na rudi od 2.5 miliona tona rude, dostigne u *drugoj godini*. U prvoj godini je planirano i otkopavanje investicione raskrivke do momenta stvaranja uslova za pokrivanje troškova raskrivanja vrednošću rude.To praktično omogućava da se u delu prerade mineralne sirovine završe radovi na revitalizaciji i pogon pripremi za normalnu proizvodnju.

Tabela 2. *Dinamika otkopavanja po godinama (periodima) prema DRP iz 2008. godine*

God	Iskopine (t)	Jalovina	Ruda	Cu uk(t)	Ag	Au	Cu uk (%)	Ag (g/t)	Cu uk (%)	Au (g/t)
1.	6,012,750	4,330,190	1,682,560	4,552.20	1,871.50	194.20	0.27	1.11	0.27	0.12
2	4,211,527	1,713,040	2,498,487	5,831.80	3,062.70	307.20	0.23	1.23	0.23	0.12
3.	5,547,786	3,049,922	2,497,865	5,948.40	2,410.90	248.90	0.24	0.97	0.24	0.10
4.	5,085,516	2,589,466	2,496,050	6,817.00	4,249.70	334.90	0.27	1.70	0.27	0.13
5.	5,888,154	3,389,624	2,498,531	7,458.50	3,284.70	229.50	0.30	1.32	0.30	0.09
6.	5,957,158	3,463,180	2,493,977	7,573.30	3,194.80	182.10	0.30	1.28	0.30	0.07
7.	4,059,750	1,427,516	2,632,234	8,136.80	3,447.10	164.80	0.31	1.31	0.31	0.06
8.	2,966,965	475,,116.0	2,491,849	8,833.90	2,280.80	162.00	0.36	0.92	0.36	0.07
9.	3,060,615	567,411	2,493,204	9,725.30	3,032.10	196.80	0.39	1.22	0.39	0.08
10	3,085,217	590,779	2,494,438	9,166.20	2,881.50	223.00	0.37	1.16	0.37	0.09
11.	2,974,106	478,970	2,495,136	7,824.00	3,107.00	155.40	0.31	1.25	0.31	0.06
12.	2,583,542	82,816	2,500,727	7,791.30	2,628.60	207.50	0.31	1.05	0.31	0.08
13.	1,657,514	8	1,657,506	5,095.80	1,768.60	166.80	0.31	1.07	0.31	0.10
SUMA	53,090,601	22,158,038	30,932,564	94,754.40	37,220.00	2,773.10	0.31	1.20	0.31	0.09

Obzirom na to da postrojenja prerade – infrastruktura u delu prerade, zahteva znatan obim radova na reparaciji i dovođenju u funkcionalno stanje, sa navedenim aktivnostima treba započeti znatno pre početka otkopavanja.

Koncepcija eksploatacije je izmenjena i promenom lokacije flotiranja u odnosu na prvobitnu. Umesto ranijeg rešenja da se flotiranje odvija u flotaciji Bor, flotiranje je sada planirano u flotaciji Veliki Krivelj što podrazumeva i promenu trase cevovoda za hidraulični transport pulpe.

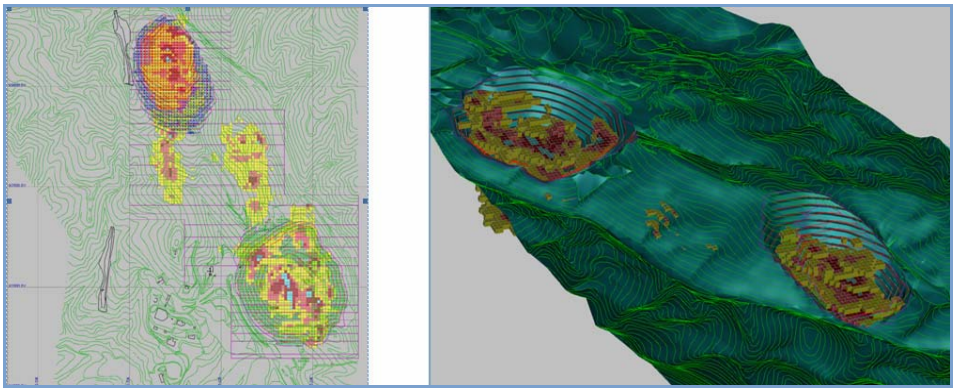
U rudarskom delu ovim projektom nije predviđena promena dosadašnje tehnologije otkopavanja, osim modifikacija u bušačko minerskim radovima u severozapadnom delu kopa C2 zbog blizine železničke pruge i to u smislu minimiziranja uticaja eksploatacije na objekte železnice.

4. VARIJANTE PRELASKA NA KAPACITET OD 5.5 Mt GODIŠNJE

Nova strategija razvoja RTB –a je svojim biznis planom kao stratešim dokumentom definisala povećanje kapaciteta sa lokacije Kraku bugaresku Cementacija, i to na 5.5 milona tona, nakon stvaranja odgovarajućih potrebnih uslova kako na kopu tako i u delu PMS. Potrebno vreme za te aktivnosti je procenjeno na 2 godine. Dakle, povećanje godišnjeg kapaciteta sa 2.5 Mt na 5.5 Mt će uslediti dve godine nakon ponovnog aktiviranja rudarskih radova na kopu (kopovima) i u flotaciji.

Postoje dve mogućnosti za nastavak otkopavanja sa povećanim kapacitetom otkopavanja.

1. *Otkopavanje Cementacije 2 u jednom zahvatu (varijanta 2F), i*
2. *Fazno otkopavanje Cementacije 2 sa dve faze C2-1 i C2-2 (varijanta 3F).*



Sl. 2. *Kopovi Cerovo Cementacija 1 i Cerovo 2, sa faznim otkopavanjem Cerova 2 (push backs C21 i C22)*
(U pozadini je geološki blok model ležišta Kraku Bugaresku, Gemcom)

Za ostvarenje prve varijante otkopavanja sa podizanjem kapaciteta otkopavanja na 5.5 miliona tona godišnje, potrebni su veći kapaciteti utovara i transporta jer je ostvarljiva intenzivnijim raskrivanjem ležišta, tj. povećanjem obima iskopa na početku otkopavanja.

U obe varijante potrebno je postrojenje za pripremu i koncentraciju osposobiti za navedeni kapacitet, što će zahtevati ulaganja koja će biti navedena u narednim tabelama. (*izvor* [6] *Biznis plan RTB Bor*).

4.1. Dinamika otkopavanja za varijantu 2F

U tabeli 3. Prikazana je dinamika otkopavanja sa radom na kopu Cementacija 1 (postojeći kop na kome je bila obustavljena eksploatacija 2004. godine) i na kopu Cementacija 2 gde se planira otkopavanje bez faznog rada.

Tabela 3. *Dinamika otkopavanja u varijanti prelaska na kapacitet 5.5 Mt godišnje bez faznog otkopavanja na Cerovu2*

Period	Tonne in place	Waste tonne	Tonne input	Grade CU	Grade AG	Grade	Units to process	Units to process	Units to process
				input	input	input	FLOT	FLOT	FLOT
				%	g/t	AU'g/t	CU t	AU kg	AG kg
1	7 000 000	4 943 885	2 056 115	0. 27	01.1	0.0001	5 579	219	2 262
2	7 000 000	4 512 181	2 487 819	0. 23	1.3	0.0001	5 692	322	3 113
3	12 000 000	6 502 351	5 497 649	0. 26	1.3	0.0001	14 197	571	7 110
4	10 106 771	4 606 771	5 500 000	0. 28	1.2	0.0001	15 132	399	6 628
5	6 502 574	1 002 574	5 500 000	0. 33	1.2	0.0001	18 243	421	6 755
6	5 803 845	303 845	5 500 000	0. 38	1.1	0.0001	20 892	416	6 212
7	5 554 089	54 089	5 500 000	0. 31	1.2	0.0001	16 778	510	6 549
8	352 807	0	352 807	0.00	1.2	0.0001	1 060	34	413
Total	**54 320 086**	**21 925 696**	**32 394 390**	**0.30**	**1.2**	**0.0893**	**97 573**	**2 892**	**39 042**

Tabela 3.1. *Dinamika otkopavanja u varijanti prelaska na kapacitet 5.5 Mt godišnje bez faznog otkopavanja na Cerovu 2*

tonne in place	*tonne to waste*	*tonne processed*	*Units to process*	*tonne in place*	*tonne to waste*	*tonne processed*	*Units to process*
PUSH1	*PUSH1*	*PUSH1*	*CU*	*PUSH2*	*PUSH2*	*PUSH2*	*CU*
C1				C22			
6 751 924	4 695 809	2 056 115	5 579	248 076	248 076		
4 250 772	1 762 953	2 487 819	5 692	2 749 228	2 749 228		
6 370 434	1 401 145	4 969 289	13 213	5 629 565	5 101 206	528 360	984
				10 106 771	4 606 771	5 500 000	15 132
2 103 259	168 921	1 934 337	6 044	4 399 315	833 653	3 565 663	12 199
876 247	68 861	807 387	2 433	4 927 598	234 985	4 692 613	18 459
2 378 379	33 623	2 344 756	6 651	3 175 710	20 466	3 155 244	10 127
				352 807		352 807	1 060
22 731 015	8 131 312	14 599 703	39 612	31 589 070	13 794 385	17 794 687	57 961

4.2. Dinamika otkopavanja za varijantu 3F

Tabela 4. *Dinamika otkopavanja u varijanti prelaska na kapacitet 5.5 Mt godišnje sa faznim otkopavanja na Cerovu 2*

				Grade	Grade	Grade	Units to process	Units to process	Units to process
Period	*tonne*	*Waste*	*tonne*	*input*	*input*	*input*	*FLOT*	*FLOT*	*FLOT*
	in place	*tonne*	*input*	*CU %*	*AG g/t*	*AU g/t*	*CU t*	*AU kg*	*AG kg*
1	7 000 000	4 846 958	2 153 042	0.271	1.11	0.110	5 829	233	2 399
2	7 000 000	4 502 294	2 497 706	0.228	1.25	0.130	5 686	320	3 114
3	12 000 000	6 500 582	5 499 418	0.249	1.17	0.100	13 703	538	6 420
4	10 921 136	5 421 136	5 500 000	0.289	1.22	0.070	15 903	364	6 727
5	6 180 653	680 653	5 499 999	0.328	1.34	0.090	18 023	494	7 378
6	5 842 773	342 773	5 500 000	0.378	1.13	0.080	20 808	414	6 239
7	5 557 354	57 354	5 500 000	0.305	1.19	0.090	16 796	508	6 518
8	542 594	0	542 594	0.300	1.17	0.090	1 629	51	637
TOTAL	**55 044 510**	**22 351 750**	**32 692 759**	**0.305**	**1.21**	**0.089**	**98 377**	**2 922**	**39 432**

Tabela 4.1. *Dinamika otkopavanja u varijanti prelaska na kapacitet 5.5 Mt godišnje sa faznim otkopavanja na Cerovu 2*

tonne	*tonne to*	*tonne*	*Units to process*	*tonne*	*tonne to*	*tonne*	*Units to process*	*tonne*	*tonne to*	*tonne*	*Units to process*
in place	*waste*	*processed*	*PUSH1*	*in place*	*waste*	*processed*	*PUSH2*	*in place*	*waste*	*processed*	*PUSH3*
PUSH1	*PUSH1*	*PUSH1*	*CU*	*PUSH2*	*PUSH2*	*PUSH2*	*CU*	*PUSH3*	*PUSH3*	*PUSH3*	*CU*
Cementacija 1				Cementacija 2-1				Cementacija 2 -2			
7 000 000	4 846 958	2 153 042	5 829	0	0	0	0	0	0	0	0
4 242 056	1 778 759	2 463 297	5 627	2 757 944	2 723 535	34 409	59	0	0	0	0
4 913 450	1 341 299	3 572 151	8 678	4 643 248	2 715 982	1 927 267	5 025	2 443 302	2 443 302	0	0
11 851	1 705	10 147	26	2 361 651	737 786	1 623 865	5 954	8 547 633	4 681 645	3 865 988	9 923
3 699 558	321 875	3 377 683	10 695	1 142 548	42 910	1 099 638	4 406	1 338 547	315 868	1 022 679	2 922
970 228	77 976	892 252	2 670	1 678 595	0	1 678 595	8 656	3 193 950	264 797	2 929 153	9 482
2 369 424	32 738	2 336 687	6 614	470 602	0	470 602	1 924	2 717 328	24 617	2 692 712	8 259
0	0	0	0	0	0	0	0	542 594	0	542 594	1 629
23 206 567	**8 401 310**	**14 805 259**	**40 139**	**13 054 588**	**6 220 213**	**6 834 376**	**26 024**	**18 783 354**	**7 730 229**	**11 053 126**	**32 215**

4.3. Investiciona ulaganja u opremu i objekte na kopu i na postrojenju PMS-a

Za kapacitet rudnika od 2.5 Mt u prve dve godine i povećanja na 5,5 Mt do kraja veka eksploatacije, po varijantama, potrebna su sledeća investiciona ulaganja:

a) Varijanta 2F

Tabela 5. *Investiciona ulaganja za pokretanje proizvodnje sa 2.5 Mt i prelazak na kapacitet 5.5 Mt godišnje na kopu Kraku bugaresku C1 i C2 (Izvor:Biznis plan RTB Bor)*

No.	Naziv	Jedinična cena US$	2011		2012		2013		2014	
			količina	vrednost	količina	vrednost	količina	vrednost	količina	vrednost
1.	**Nabavka nove opreme**			**5,554,000**		**8,184,000**		**14,877,000**		**13,331,000**
	- Postrojenja pripreme i prerade					3,530,000		6,189,000		10,331,000
	- Drobilično postrojenje za rudu									1,000,000
	- Bušilica D=200mm	650,000	1	650,000	1	650,000	1	650,000		
	- Hudraulični bager V=10m^3	2,000,000	1	2,000,000		0	1	2,000,000	1	2,000,000
	- Kamion Nosivosti 150 t	1,452,000	2	2,904,000	2	2,904,000	4	5,808,000		
	- Buldozer 375 KS	893,750		0	1	893,000		0		
	- Grejder 16 G	500,000		0	1	500,000		0		
	- Pomoćna mehanizacija			0		0		230,000		
2.	**Sanacija, rekonstrukcija i dogradnja**			**5,350,000**		**3,300,000**		**1,485,500**		**0**
	- Revitalizacija post.pripreme i prerade			2,650,000		0		0		
	- Sanacija postojećeg hidrotransporta			2,700,000		3,300,000		0		
3.	Izrada postr. za prečiš.otpadnih voda			0		1,570,000		0		
4.	Ostala investiciona ulaganja			0		0		1,485,000		
5.	Eksproprijacija			0		0		0		750,000
	Ukupno kop Cerovo po godinama			**10,904,000**		**13,287,000**		**16,362,000**		**14,081,000**
	UKUPNO	**54,634,000.00 US$**								

b. Varijanta 3F

Tabela 5.1. *Investiciona ulaganja za pokretanje proizvodnje 2.5 Mt i prelazak na kapacitet 5.5 Mt godišnje na kopu Kraku bugaresku C1 i C 2 sa ukupno 3 faze*

No.	Naziv	Jedinična cena US$	2011		2012		2013		2014	
			količina	vrednost	količina	vrednost	količina	vrednost	količina	vrednost
1.	**Nabavka nove opreme**			**5,554,000**		**10,477,000**		**11,973,000**		**11,331,000**
	- Postrojenja pripreme i prerade					3,530,000		6,189,000		10,331,000
	- Drobilično postrojenje za rudu									1,000,000
	- Bušilica D=200mm	650,000	1	650,000	1	650,000	1	650,000		
	- Hudraulični bager V=10m^3	2,000,000	1	2,000,000	1	2,000,000	1	2,000,000		
	- Kamion Nosivosti 150 t	1,452,000	2	2,904,000	2	2,904,000	2	2,904,000		
	- Buldozer 375 KS	893,750		0	1	893,000		0		
	- Grejder 16 G	500,000		0	1	500,000		0		
	- Pomoćna mehanizacija			0		0		230,000		
2.	**Sanacija, rekonstrukcija i dogradnja**			**5,350,000**		**3,300,000**		**0**		**0**
	- Revitalizacija post.pripreme i prerade			2,650,000		0		0		
	- Sanacija postojećeg hidrotransporta			2,700,000		3,300,000		**0**		
3.	Izrada postr. za prečiš.otpadnih voda			**0**		**1,570,000**		**0**		
4.	Ostala investiciona ulaganja			**0**		**0**		**1,485,000**		
5.	Eksproprijacija			**0**		**0**		**0**		**750,000**
	Ukupno kop Cerovo po godinama			**10,904,000**		**15,347,000**		**13,458,000**		**12,081,000**
	UKUPNO					**51,790,000.00**				

5. OSVRT NA TEORIJSKE OSNOVE METODE „ANALIZA OSETLJIVOSTI INTERNE STOPE RENTABILNOSTI PROJEKTA“

Analiza osjetljivosti projekta ima cilj da proceni prihvatljivost projekta ako vrednosti kritičnih parametara projekta budu drugačije nego što je planirano pri projektovanju.

Metoda interne stope rentabilnosti (profitabilnosti) (*engl. internal rate of return method*, *njem. interne Zinssatzmethode*) je metoda za ocjenu prihvatljivosti investicionog ulaganja, koristi internu stopu rentabilnosti kao meru delotvornosti projekta. Interna stopa rentabilnosti definiše se kao ona diskontna stopa koja neto sadašnju vrednost svodi na nulu, a određuje se prema matematičkom obrascu. Pri izračunavanju interne stope rentabilnosti analitičari se služe iterativnim postupkom, grafičkim postupkom ili interpolacijom. U ovom slučaju IRR je na osnovu ulaganja sračunata i analizirana u softveru za ekonomsku optimizaciju i strateško planiranje na ležištima mineralnih sirovina - *Whittle Fx*.

Tumačenje interne stope rentabilnosti zavisi od kombinacije izvora finansiranja. Ako u finansiranju investicija učestvuje samo vlastiti kapital, tada je to stopa po kojoj on odbacuje prosečnu akumulaciju. Ako se koriste i krediti, tada će i vlastiti i tuđi izvori finansiranja stvarati povrat po toj stopi u odnosu na svoju veličinu.

Kada se investicioni projekt finansira samo iz kredita, tada tuđi kapital po internoj stopi rentabilnosti odbacuje prosečnu godišnju akumulaciju, pa je to ujedno i maksimalno prihvatljiva kamatna stopa na kredite. Interna stopa rentabilnosti ima značenje maksimalno prihvatljive kamatne stope na kredite, nezavisno od toga da li u finansiranju učestvuje vlastiti kapital ili ne. Nezavisno dakle od strukture izvora finansiranja, internu stopu rentabilnosti treba tumačiti kao maksimalno prihvatljivu kamatnu stopu na kredite. Prednost metode je u tome što pruža informaciju o maksimalno prihvatljivoj prosečnoj godišnjoj kamatnoj stopi na ukupne izvore finansiranja, i to pod uslovom da se finansijske obveze na osnovu njih otplaćuju tokom celog veka projekta. Ako je reč o kreditu, to znači da interna stopa rentabilnosti daje informaciju o maksimalno prihvatljivoj kamatnoj stopi na kredite, čija otplata traje do kraja veka projekta. Ako je reč o vlastitom kapitalu, to je prosečna godišnja stopa njegovog povraćaja tokom celog veka projekta, što znači da ta

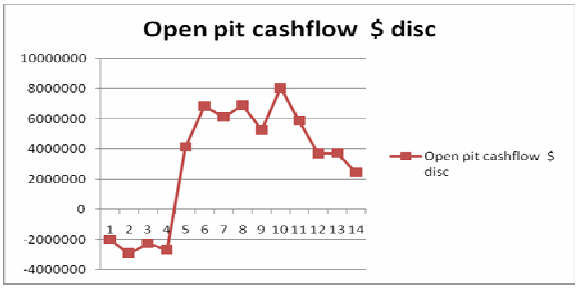
stopa određuje i maksimalni iznos **dobiti** koja se može podeliti vlasnicima.

U ovom slučaju, kritični parametar čiji se uticaj na efektivnost investicije analizira (odnosno IRR), jeste *koeficijent iskorišćenja Cu iz rude u flotaciji*. tj. konkretnije, uticaj broja faza otkopavanja na kopu na koeficijent iskorišćenja Cu iz rude u flotaciji, podrazumevajući da se doziranje rude sa kopa vrši usrednjavanjem sadržaja Cu ili pravljenjem kompozita odnosno *blendingom.*

6. PRIKAZ FINALNIH EKONOM SKIH REZULTATA ZA POJEDINE VARIJANTE OTKOPAVANJA KB CEMENTACIJA 1 I 2

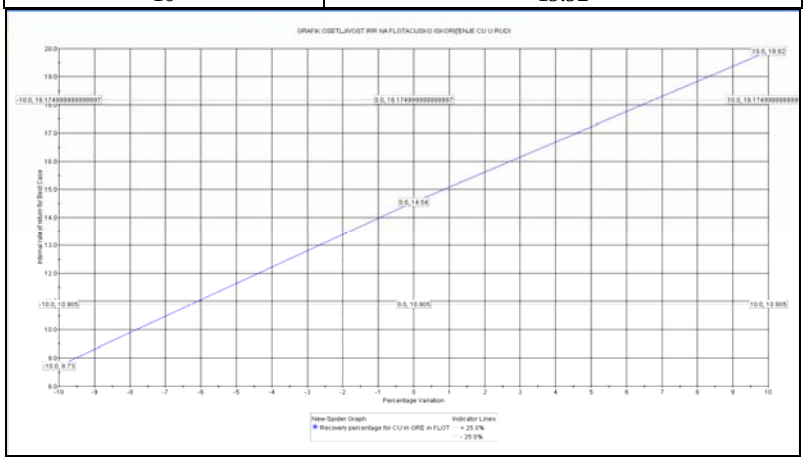
a) Varijanta iz DRP-a sa konstantnim godišnjim kapacitetom 2.5 Mt
b) Varijanta 2F sa kapacitetom 2.5 /5.5 Mt godišnje,
c) Varijanta 3F sa kapacitetom 2.5 /5.5 Mt godišnje.

A) *Varijanta prema DRP za 2.5 Mt godišnje i otkopavanjem na C1, C2-1 i C2-2*



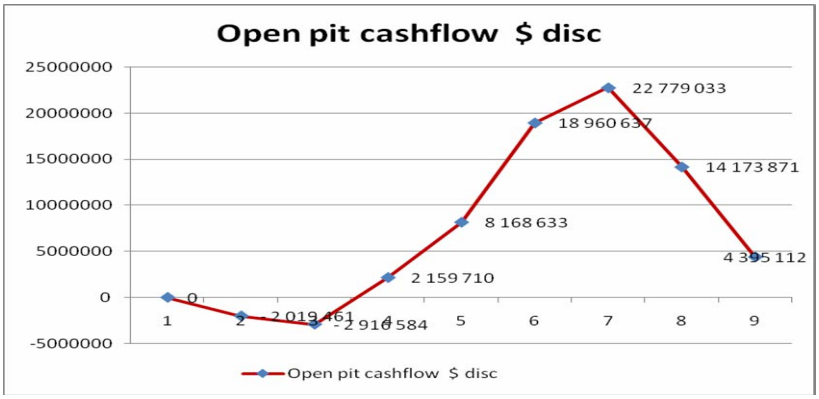
Grafik 2. *Grafik NPV diskontovan za varijantu 2.5 mt sa 3 faze, vek eksploatacije 15 godina, Df=10%*

% Variation	Recovery percentage for Cu in ORE in FLOT
-10	8.73
0	14.54
10	19.92



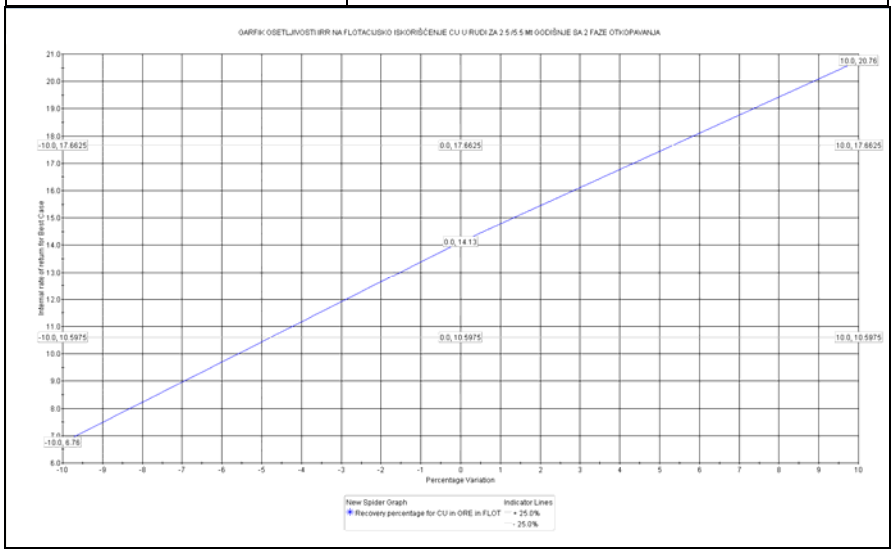
Grafik 3. *Osetljivost IRR na flotacijsko iskorišćenje u slučaju varijante 3 F i kapacitetom 2.5 Mt godišnje*

B) ***Varijanta 3F sa kapacitetom 2.5/5.5 Mt godišnje i otkopavanjem na C1 i C2-2***



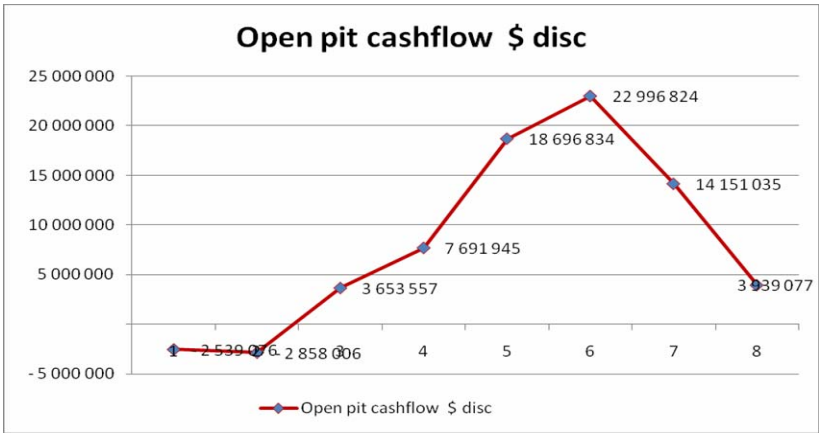
Grafik 4. *Diskontovana vrednost kopa (NPV) za varijantu 3F (fazno otkopavanje C2), Df=10%*

% Variation	Recovery percentage for Cu in ORE in FLOT
-10	6.67
0	14.13
10	20.76



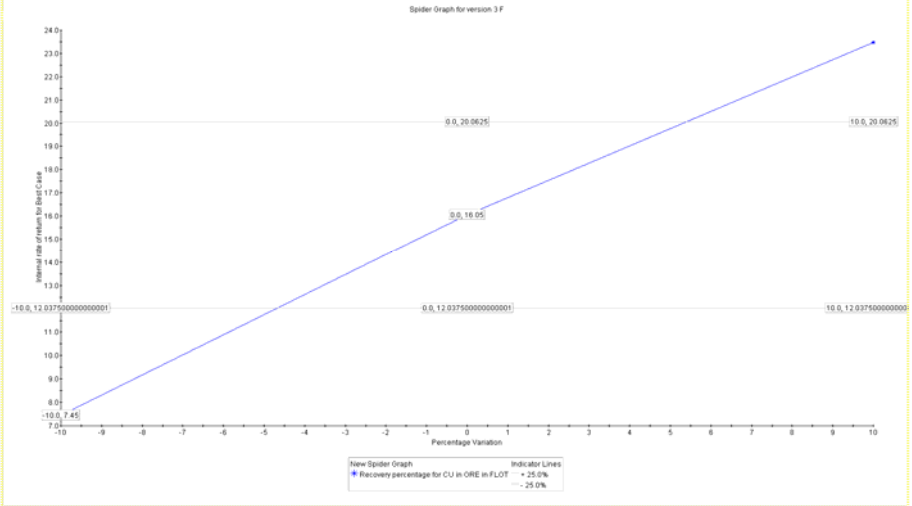
Grafik 5. *Grafik osetljivosti IRR projekta Cerovo na flotacijsko iskorišćenje u slučaju otkopavanja sa 2 faze (push backs) i kapacitetom 2.5/5.5 Mt godišnje*

C) ***Varijanta 3F sa kapacitetom 2.5 /5.5 Mt godišnje i otkopavanjem na C1, C2-1 i C2-2***



Grafik 6. *Diskontovana vrednost kopa (NPV) za varijantu 3F (fazno otkopavanje C2), Df=10%*

% Variation	Recovery percentage for Cu in ORE in FLOT
-10	7.45
0	16.05
10	23.48



Grafik 7. *Grafik osetljivosti IRR projekta Cerovo na flotacijsko iskorišćenje u slučaju otkopavanja sa 3 faze sa kapacitetom 2.5/5.5 Mt godišnje*

7. ZAKLJUČAK

U varijanti otkopavanja „3F“ smanjenjem koeficijenta iskorišćenja za 10%, IRR se smanjuje 8.6, dok promenom istog koeficijenta za +10%, IRR se povećava za 7.45, tj. vrednost promene je $\Delta \pm$ IRR = 0.15;

U varijanti „2F“, smanjenjem koeficijenta iskorišćenja u flotaciji za 10 %, IRR se smanjuje za 7.46, dok povećanjem $I_{f\,z}$ za 10%, IRR se povećava za 6.63. i vrednost promene iznosi $\Delta \pm$ IRR = 0.23.

Ovako posmatrajući, varijanta 2F je osetljivija na promene flotacijskog iskorišćenja.

Bez obzira na prikazane rezultate analize, otkopavanje sa više faza omogućava kvalitetno stvaranje kompozita rude prema flotaciji zbog mogućnosti istovremenog rada na više otkopnih čela.

Obzirom da program Whittle prilikom klasične optimizacije bez korišćenja *stockpila* ne prepoznaje prevelike razlike prilikom otkopavanja u ovakvim slučajevima, potrebno je detaljno obraditi dinamiku otkopavanja sa opcijom „*Extractiv Blend Scenario*“ koji omogućava optimizaciju flotacijskog iskorišćenja metala ili korišćenjem stockpile ili stvaranjem mogućnosti da postoji više aktivnih otkopnih čela na rudi (sa različitim sadržajima metala).

LITERATURA

[1] Glavni projekat otkopavanja ležišta „Cerovo – Cementacija“ za godišnji kapacitet 2,5 x 10^6 tona rude, knjiga I-1, Eksploatacija rude površinskim kopom Institut za bakar Bor, 1991. godine

[2] Dopunski rudarski projekat otkopavanja rude bakra iz ležišta „Cerovo cementacija – Kraku bugaresku“ za godišnji kapacitet 2.5 x 10^6 tona godišnje sa verifikacijom opreme za pripremu mineralnih sirovina, Institut za rudarstvo i metalurgiju Bor, Novembar 2008, godine. Odgovorni projektant Z. Vaduvesković; Tehnička kontrola projekta RGF Bdeograd (prof. B. Kolonja).

[3] Leksikon menedžmenta, F. Bahtijarević Šiber, P. Sikavica, Masmedia Zagreb, 2001

[4] Gemcom Whittle User Manuel

[5] Studija kombinovane eksploatacije rude bakra na ležištu Kraku bugaresku – cementacija i Cerovo, IRM Bor, 2009. Odgovorni projektant: Z.Vaduvesković

[6] Biznis plan za proizvodnju bakra za period 2011-2021.godine, RTB Bor, Bor, 16. jun 2011. god.

UDK: 622.06:622.7:622.221(045)=20

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CONTINUATION THE MINING ACTIVITIES OF RTB BOR ON LOCATION KRAKU BUGARESKU CEMENTATION WITH THE SENSITIVITY ANALYSIS OF IRR SELECTION THE MINING VARIANTS[***]

Abstract

This paper describes the activities on exploitation resumption at Kraku Bugaresku Cementation 1 and 2 site, with a short review of the history of previously realized and current state of mining activities, as well as the concept of the future exploitation.

The investor plans changes in the concept of future exploitation in terms of annual productivity increase (5.5 Mt) compared to the designed 2.5 Mt as well as reduction of the number of stages (push backs) in the development of the open pit Cementation 2. The article presents the sensitivity analysis of the IRR and the consequences of the reduction in the number of working sites in simultaneous operation. In other words, the exploitation with smaller number of push backs reduces the possibility of ore blending, affecting the coherence of metal grade in the ore fed to flotation, i.e. the recovery in the flotation. Reduction the efficiency reduces the income and thus affects the IRR as one of the indicators of economic evaluation of the project.

***Keywords**: exploitation, state of mining operations, push backs, flotation recovery, IRR, investments, return on investments*

INTRODUCTION

Copper ore deposit Kraku Bugaresku - Cerovo is located in the East Serbia, some 20 km north of Bor (Figure 1).

Mining operations in the complex of Cerovo ore deposits (Cerovo Cementation 1, Cerovo 2, Cerovo 3, Cerovo 4, Cerovo Primary and Drenova), started in 1990 with the open pit Cerovo Cementation 1. During investment stripping, which lasted from 1990 to 1993 and covered the construction of processing facilities at the site and the hydro-transport system to the Bor flotation

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plant, nearly 10 Mt of overburden was stripped (nearly half of total amount of overburden in the pit outline). That created very favorable conditions for subsequent exploitation with a low striping ratio. This obviously had its price, but the circumstances were such that it actually made Cerovo to operate in very difficult and almost impossible conditions, with very unfavorable market conditions, when the price of copper was even incredible 1300 US$ per ton of cathode copper (2002).

The Main Mine Design of "Cerovo Cementation 1" [1] defined the following recoverable reserves within the 0.3% Cu contour of Cerovo Cementation 1 open pit:

- Ore ----------17,479,165 t,
- Waste ----------23,674,605 t,
- Excavations ----------41,153,770 t,
- Mean Cu content in the ore ----------0.713 % Cu,
- Mean overburden coefficient ----------1.35 t/t.

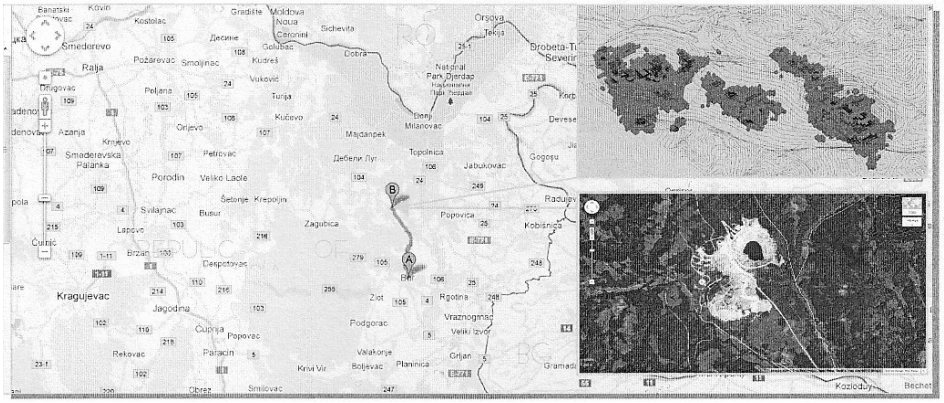

Fig. 1. *Position of the copper ore deposit "KB-Cementation" RTB Bor (Google map)*

1. PREVIOUS MINING ACTIVITIES AT KRAKU BUGARESKU – CEROVO DEPOSIT

The concept of mining considered drilling and blasting and cyclic haul-truck haulage of ore and waste. Designed bench height was 15 m, the spiral roads starting at the northwest side of the pit, at elevation of K+515 m, at the location where pit passes from the mountain into deep type. Road width was 20 m, and ramp slope 10%.

The ore was hauled to primary crusher and then stocked in a closed depot. The next technological phase was secondary and tertiary crushing. Crushed ore was fed to the next phase, two stages of milling. Cerovo did not have fully developed flotation. The process ended with the pulp which was, after thickening, hydraulically transported to the Bor Flotation Plant, where flotation was carried out. The tailings were dumped at the flotation tailing dump RTH in Bor.

The problem of equipment replacement dynamics and maintenance quality due to a lack of spare parts arose in the mining industry during the ninety-nineties because of known limited economic conditions and culminated during 2003 and 2004, when all mining operations at Cerovo were terminated. The intention was to carry out conservation of remaining equipment and installations and to some extent it has been done. The rest of mining mechanization from Cerovo was transferred to Veliki Krivelj in an attempt to maintain even minimum possible production.

Mining works at the open pit Cerovo Cementation 1 stopped at elevation of K+395 m (bench 395). Dewatering continued for some time but eventually it came to a caese. Presently the pit floor is flooded Fig. 1), and technical design of dewatering will define the terms and method for the removal of the water accumulated at the pit floor, with the aim of creating conditions for production resumption.

Revitalization and resumption of production started during 2011/2012, but with a slightly different concept than previously defined, both from the aspect annual capacity of ore extraction and processing, and from the aspect of mining concept of the Cerovo 2, that is the overall dynamics.

2. THE CONCEPT OF MINE REVIVAL

Since, during the last several years, copper market recovered and copper price at one point reached 9 000 US$, even relatively low-grade deposits became more at tractive and economically viable for mining. Strategy of reactivation of the copper ore mining at Cerovo - Kraku Bugaresku is degned by the *Supplementary Mining Design of Excavation in 2008,* [2] , and it considers expansion and deepening of the Cerovo Cementation 1 open pit, and opening and mining operations start at Cementation 2 deposit.

Optimization resulted in selection of pit contours and the optimum long-term dynamics of excavation according to the criterion of profit and discounted profit for future mining period using the software Whittle Fx. The technical design of mining (SMD 2008), discussed the above procedure in detail, with the exception of mine capacity limited (at the request of the Investor) by the existing flotation processing capacity of 2.5 x 10^6 t of ore.

Starting parameters used in the optimization and resulting graph as output of optimization process in Whittle Fx are given in figure 2.

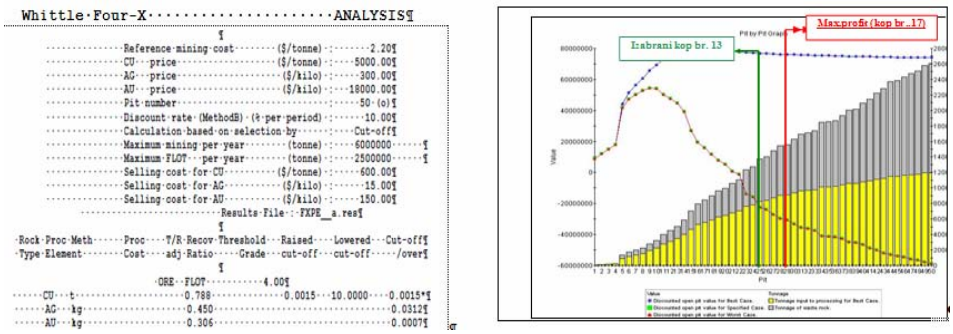

Fig. 2. *Input parameters of optimization and graph with a review of profit and discounted profit, and possible pit contours (50) for different prices of Cu*

As it can be seen from the graph given in Fig. 2 curves of profit and discounted profit heavily diverge with increase in production, indicating excavation with push backs.

List of planned mining equipment for the achievement of annual capacity of 2.5 Mt is shown in Table 1:

Table 1. *Mining equipment planned by the SMD for the complex of Cerovo Kraku Bugaresku ore bodies*

No	Name of equipment	Characteristics	Type and designation	Pcs.
1	Drill, diameter 250 mm	Rb=250 mm	Atlas Copco	1
2	Drill, diameter 89 - 130 mm	R89 do 130 mm	Atlas Copco	1
3	Hydraulic excavator with electric drive	V_K= 10 m^3	Terex -OK	1
4	Loader L-950	V_K=13 m^3	Leturnoau	1
5	Truck - dumper	Capacity 90 Mt	HD785-7 Komatsu	6
6	Bulldozer crawler	CAT 249 KW)	CAT	2
7	Loader	249 KW	CAT 16H	1
8	Water cistern FAP1823	V=9 m3		1
9	Service vehicle FAP1318/42	Capacity 8 t		2
10	Service-terrain vehicle		Lada Niva	2
11	Submersible slurry pumps	Flyght	BS 25.00	4
12	Wheel loader	V = 2.5 – 3		1

The concept of future work is to start stripping operations at Cementation 1 open pit in *the first year* creating the necessary conditions for achievement of full designed annual productivity of 2.5 Mt of ore as early as the second year. Investment stripping should carry on until the moment the necessary conditions to cover stripping operations by extracted ore are met. This would allow finalization of the works on revitalization in a part of mineral processing and preparation plant for normal production.

Table 2. *Dynamics of excavation per years (periods) according to SMD from 2008*

Year	Excavations (t)	Waste	Ore	Cu Total(t)	Ag	Au	Cu Total (%)	Ag (g/t)	Cu Total (%)	Au (g/t)
1.	6,012,750	4,330,190	1,682,560	4,552.20	1,871.50	194.20	0.27	1.11	0.27	0.12
2	4,211,527	1,713,040	2,498,487	5,831.80	3,062.70	307.20	0.23	1.23	0.23	0.12
3.	5,547,786	3,049,922	2,497,865	5,948.40	2,410.90	248.90	0.24	0.97	0.24	0.10
4.	5,085,516	2,589,466	2,496,050	6,817.00	4,249.70	334.90	0.27	1.70	0.27	0.13
5.	5,888,154	3,389,624	2,498,531	7,458.50	3,284.70	229.50	0.30	1.32	0.30	0.09
6.	5,957,158	3,463,180	2,493,977	7,573.30	3,194.80	182.10	0.30	1.28	0.30	0.07
7.	4,059,750	1,427,516	2,632,234	8,136.80	3,447.10	164.80	0.31	1.31	0.31	0.06
8.	2,966,965	475,116.0	2,491,849	8,833.90	2,280.80	162.00	0.36	0.92	0.36	0.07
9.	3,060,615	567,411	2,493,204	9,725.30	3,032.10	196.80	0.39	1.22	0.39	0.08
10	3,085,217	590,779	2,494,438	9,166.20	2,881.50	223.00	0.37	1.16	0.37	0.09
11.	2,974,106	478,970	2,495,136	7,824.00	3,107.00	155.40	0.31	1.25	0.31	0.06
12.	2,583,542	82,816	2,500,727	7,791.30	2,628.60	207.50	0.31	1.05	0.31	0.08
13.	1,657,514	8	1,657,506	5,095.80	1,768.60	166.80	0.31	1.07	0.31	0.10
TOTAL	53,090,601	22,158,038	30,932,564	94,754.40	37,220.00	2,773.10	0.31	1.20	0.31	0.09

Since the processing plant i.e. the ore processing infrastructure, requires a considerable amount of works on reconstruction and revitalization to operational state, these ac-

tivities should begin before the start of mining operations.

Mining concept is also modified in a way to change the location of ore flotation. Instead of previous operations when ore was processed in the Bor Flotation Plant, the ore will now be processed in the Veliki Krivelj Flotation Plant which requires the construction of new pipeline route for hydraulic transport of pulp.

Changes in current mining technology are not anticipated, except modifications in drill and blast operations in the N-W of the C2 open pit. The proximity of railroad requires minimization the adverse effects of blasting operations in terms of ground vibrations and flyrock.

3. VARIANTS OF TRANSITION TO ANNUAL PRODUCTIVITY OF 5.5 Mt

The new strategy of RTB development, with its business plan as a strategic document, defined the capacity increase at Kraku Bugaresku Cementation to 5.5 million t, after creating the appropriate necessary conditions at both the open pit and in a part of mineral processing. The required time for these activities is estimated to two years. Thus, increasing the annual capacity from 2.5 Mt to 5.5 Mt will follow two years after reactivation of the mining activities at the open pit and Flotation Plant.

There are two possibilities for resumption of mining with the increased capacity.

1. ***Variant 2F*** *- Mining of Cementation 2 in one phase which includes two open pits: Cerovo cementation 1 (abbr. C_1) and Cerovo cementation 2 or (abbr.C_2) and*
2. ***Variant 3F*** *- Mining of Cementation 2 in two phases, this means that there are total of three phases – the first push back is C_1 and another two push backs are at Cementation 2 ($C_{2\text{-}1}$ and $C_{2\text{-}2}$)*

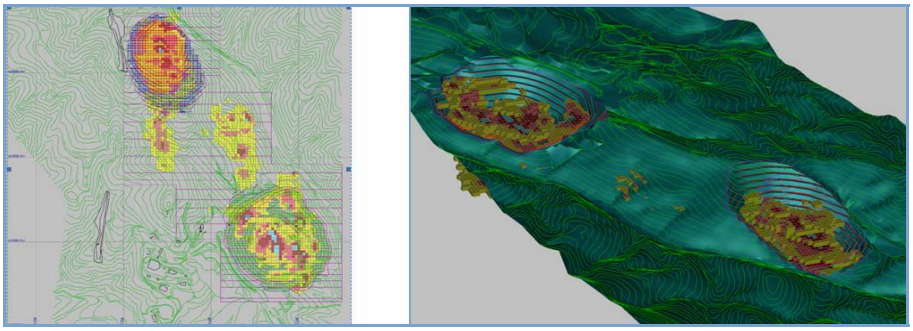

Fig. 3. *Open pits Cerovo Cementation 1and Cerovo 2, with stage mining of Cerovo 2 (pushbacks C21 and C22)*

Realization of the first variant of mining with annual productivity increased to 5.5 million t requires higher capacities of loading and hauling because it is only viable by more intensive stripping operations, i.e. increased volume of excavation at the start of mining operations.

In both variants, it is necessary to provide an ore processing plant for the listed capacity, which will require significant investments (Tables 5 and 5.1). *(Source Business Plan of RTB Bor, [6]).*

3.1. Dynamics of mining for variant 2F

Table 3 shows the dynamics of mining with operations at the Cementation 1 open pit (the existing open pit where mining was suspended in 2004) and the Cementation 2 open pit where mining is planned without the stage (phase or push backs) mining.

Table 3. *Mining dynamics at Cerovo 2 – single phase mining*

Period	Tonne in place	Waste tonne	Tonne input	Grade CU input %	Grade AG input g/t	Grade input AU'g/t	Units to process FLOT CU t	Units to process FLOT AU kg	Units to process FLOT AG kg
1	7 000 000	4 943 885	2 056 115	0. 27	01.1	0.0001	5 579	219	2 262
2	7 000 000	4 512 181	2 487 819	0. 23	1.3	0.0001	5 692	322	3 113
3	12 000 000	6 502 351	5 497 649	0. 26	1.3	0.0001	14 197	571	7 110
4	10 106 771	4 606 771	5 500 000	0. 28	1.2	0.0001	15 132	399	6 628
5	6 502 574	1 002 574	5 500 000	0. 33	1.2	0.0001	18 243	421	6 755
6	5 803 845	303 845	5 500 000	0. 38	1.1	0.0001	20 892	416	6 212
7	5 554 089	54 089	5 500 000	0. 31	1.2	0.0001	16 778	510	6 549
8	352 807	0	352 807	0.00	1.2	0.0001	1 060	34	413
	54 320 086	**21 925 696**	**32 394 390**	**0.30**	**1.2**	**0.0893**	**97 573**	**2 892**	**39 042**

Table 3.1. *Mining dynamics at Cerovo 2 – single phase mining, details*

tonne in place PUSH1	tonne to waste PUSH1	tonne processed PUSH1	Units to process PUSH1 CU	tonne in place PUSH2	tonne to waste PUSH2	tonne processed PUSH2	Units to process PUSH2 CU
C1				C22			
6 751 924	4 695 809	2 056 115	5 579	248 076	248 076		
4 250 772	1 762 953	2 487 819	5 692	2 749 228	2 749 228		
6 370 434	1 401 145	4 969 289	13 213	5 629 565	5 101 206	528 360	984
				10 106 771	4 606 771	5 500 000	15 132
2 103 259	168 921	1 934 337	6 044	4 399 315	833 653	3 565 663	12 199
876 247	68 861	807 387	2 433	4 927 598	234 985	4 692 613	18 459
2 378 379	33 623	2 344 756	6 651	3 175 710	20 466	3 155 244	10 127
				352 807		352 807	1 060
22 731 015	8 131 312	14 599 703	39 612	31 589 070	13 794 385	17 794 687	57 961

3.2. Dynamics of mining for variant 3F

Table 4. *Table 4 Mining dynamics at Cerovo 2 – phase mining*

Period	tonne in place	Waste tonne	tonne input	Grade input CU %	Grade input AG g/t	Grade input AU g/t	Units to process FLOT CU t	Units to process FLOT AU kg	Units to process FLOT AG kg
1	7 000 000	4 846 958	2 153 042	0.271	1.11	0.110	5 829	233	2 399
2	7 000 000	4 502 294	2 497 706	0.228	1.25	0.130	5 686	320	3 114
3	12 000 000	6 500 582	5 499 418	0.249	1.17	0.100	13 703	538	6 420
4	10 921 136	5 421 136	5 500 000	0.289	1.22	0.070	15 903	364	6 727
5	6 180 653	680 653	5 499 999	0.328	1.34	0.090	18 023	494	7 378
6	5 842 773	342 773	5 500 000	0.378	1.13	0.080	20 808	414	6 239
7	5 557 354	57 354	5 500 000	0.305	1.19	0.090	16 796	508	6 518
8	542 594	0	542 594	0.300	1.17	0.090	1 629	51	637
TOTAL	**55 044 510**	**22 351 750**	**32 692 759**	**0.305**	**1.21**	**0.089**	**98 377**	**2 922**	**39 432**

Table 4.1. *Table 4 Mining dynamics at Cerovo 2 – phase mining, details*

tonne	*tonne to*	*tonne*	*Units to process*	*tonne*	*tonne to*	*tonne*	*Units to process*	*tonne*	*tonne to*	*tonne*	*Units to process*
in place	*waste*	*processed*	*PUSH1*	*in place*	*waste*	*processed*	*PUSH2*	*in place*	*waste*	*processed*	*PUSH3*
PUSH1	*PUSH1*	*PUSH1*	*CU*	*PUSH2*	*PUSH2*	*PUSH2*	*CU*	*PUSH3*	*PUSH3*	*PUSH3*	*CU*
Cementacija 1				Cementacija 2-1				Cementacija 2 -2			
7 000 000	4 846 958	2 153 042	5 829	0	0	0	0	0	0	0	0
4 242 056	1 778 759	2 463 297	5 627	2 757 944	2 723 535	34 409	59	0	0	0	0
4 913 450	1 341 299	3 572 151	8 678	4 643 248	2 715 982	1 927 267	5 025	2 443 302	2 443 302	0	0
11 851	1 705	10 147	26	2 361 651	737 786	1 623 865	5 954	8 547 633	4 681 645	3 865 988	9 923
3 699 558	321 875	3 377 683	10 695	1 142 548	42 910	1 099 638	4 406	1 338 547	315 868	1 022 679	2 922
970 228	77 976	892 252	2 670	1 678 595	0	1 678 595	8 656	3 193 950	264 797	2 929 153	9 482
2 369 424	32 738	2 336 687	6 614	470 602	0	470 602	1 924	2 717 328	24 617	2 692 712	8 259
0	0	0	0	0	0	0	0	542 594	0	542 594	1 629
23 206 567	**8 401 310**	**14 805 259**	**40 139**	**13 054 588**	**6 220 213**	**6 834 376**	**26 024**	**18 783 354**	**7 730 229**	**11 053 126**	**32 215**

3.3. Investments in equipment and facilities at the open pit and mineral processing plant

Necessary investments required to achieve annual productivity of 2.5 Mt during first two years, increase the productivity to 5.5 Mt and maintain it during mine lifespan are given in tables 5 and 5.1.

a) Variant 2F

Table 5. *Investments required for variant 2F*

No.	Naziv	Jedinična cena US$	2011		2012		2013		2014	
			količina	vrednost	količina	vrednost	količina	vrednost	količina	vrednost
1.	**Nabavka nove opreme**			**5,554,000**		**8,184,000**		**14,877,000**		**13,331,000**
	- Postrojenja pripreme i prerade					3,530,000		6,189,000		10,331,000
	- Drobilično postrojenje za rudu									1,000,000
	- Bušilica D=200mm	650,000	1	650,000	1	650,000	1	650,000		
	- Hudraulični bager V=10m^3	2,000,000	1	2,000,000		0	1	2,000,000	1	2,000,000
	- Kamion Nosivosti 150 t	1,452,000	2	2,904,000	2	2,904,000	4	5,808,000		
	- Buldozer 375 KS	893,750		0	1	893,000		0		
	- Grejder 16 G	500,000		0	1	500,000		0		
	- Pomoćna mehanizacija			0		0		230,000		
2.	**Sanacija, rekonstrukcija i dogradnja**			**5,350,000**		**3,300,000**		**1,485,500**		**0**
	- Revitalizacija post.pripreme i prerade			2,650,000		0		0		
	- Sanacija postojećeg hidrotransporta			2,700,000		3,300,000		0		
3.	Izrada postr. za prečiš.otpadnih voda			0		1,570,000		0		
4.	Ostala investiciona ulaganja			0		0		1,485,000		
5.	Eksproprijacija			0		0		0		750,000
	Ukupno kop Cerovo po godinama			**10,904,000**		**13,287,000**		**16,362,000**		**14,081,000**
	UKUPNO	**54,634,000.00 US$**								

b) Variant 3F

Table 5.1. *Investments for variant 3F*

No.	Naziv	Jedinična cena US$	2011		2012		2013		2014	
			količina	vrednost	količina	vrednost	količina	vrednost	količina	vrednost
1.	**Nabavka nove opreme**			**5,554,000**		**10,477,000**		**11,973,000**		**11,331,000**
	- Postrojenja pripreme i prerade					3,530,000		6,189,000		10,331,000
	- Drobilično postrojenje za rudu									1,000,000
	- Bušilica D=200mm	650,000	1	650,000	1	650,000	1	650,000		
	- Hudraulični bager V=10m^3	2,000,000	1	2,000,000	1	2,000,000	1	2,000,000		
	- Kamion Nosivosti 150 t	1,452,000	2	2,904,000	2	2,904,000	2	2,904,000		
	- Buldozer 375 KS	893,750		0	1	893,000		0		
	- Grejder 16 G	500,000		0	1	500,000		0		
	- Pomoćna mehanizacija			0		0		230,000		
2.	**Sanacija, rekonstrukcija i dogradnja**			**5,350,000**		**3,300,000**		**0**		**0**
	- Revitalizacija post.pripreme i prerade			2,650,000		0		0		
	- Sanacija postojećeg hidrotransporta			2,700,000		3,300,000		**0**		
3.	Izrada postr. za prečiš.otpadnih voda			**0**		**1,570,000**		**0**		
4.	Ostala investiciona ulaganja			**0**		**0**		**1,485,000**		
5.	Eksproprijacija			**0**		**0**		**0**		**750,000**
	Ukupno kop Cerovo po godinama			**10,904,000**		**15,347,000**		**13,458,000**		**12,081,000**
	UKUPNO					**51,790,000.00**				

4. REVIEW OF THE THEORETICAL BASIS OF THE "SENSITIVITY ANALYSIS OF THE IRR OF THE PROJECT"

Sensitivity analysis of the Project is aimed to evaluate the acceptability of the Project if the values of critical parameters of the Project are different than planned in the design.

Internal rate of return (profitability) method is a method for assessing the acceptability of the investments, and it is used for internal rate of return as a measure of the project effectiveness. Internal rate of return is defined as discount rate that reduces the net present value to zero, and it is determined by mathematical form. When calculating the IRR, analysts use an iterative procedure, graphical method or interpo-lation. In this case, the IRR is calculated and analyzed on the basis of investments using software for economic optimization and strategic planning - *Whittle Fx.*

Interpretation of the IRR depends on a combination of funding sources. If only own capital participates in funding the investments, then this is the rate at which it rejects the average accumulation. If the loans are used, then own and other sources of funding will create the return per that rate in relation to its size.

When the investment project is financed only from the loan, then other capital per internal rate of return rejects the average annual accumulation, and this is also the maximum acceptable interest rate on loans. Internal rate of return has the meaning of maximum acceptable interest rate on loans, regardless of whether the own capital participates in funding or not. Therefore, independently of the structure of funding sources, the internal rate of return should be interpreted as maximum acceptable interest rate on loans. The advantage of this method is that it provides information on maximum acceptable average annual interest rate on total sources of financing, and under a condition that financial obligations are paid, during the entire life of the project. If it is a loan, this means that the internal rate of return provides information on maximum acceptable interest rate on loans, whose payment lasts until the end of life of the project. If it is own capital, it is an average annual rate of its return throughout the entire life of the project, what means that this rate determines the maximum amount of **profit** that can be distributed to the owners.

In this case, the critical parameter, whose influence on the effectiveness of the investments is analyzed (i.e. IRR), is the *coefficient of Cu recovery from the ore in the flotation*, that is specifically, the impact of the number of mining stages at the open pit on Cu recovery coefficient from the ore in the flotation, including the ore feeding from the open pit is done by averaging the content of Cu or making a composite or *blending*.

I - REVIEW OF THE FINAL ECONOMIC RESULTS FOR SOME MINING VARIANTS FOR KB CEMENTATION 1 AND 2

a) Variant from SMD with constant annual productivity of 2.5 Mt,
b) Variant 2F with annual productivity of 2.5 /5.5,
c) Variant 3F with annual productivity of 2.5 /5.5 Mt.

A. *Variant according to the SMD for 2.5 Mt annually and mining at C1, C2-1 and C2-2*

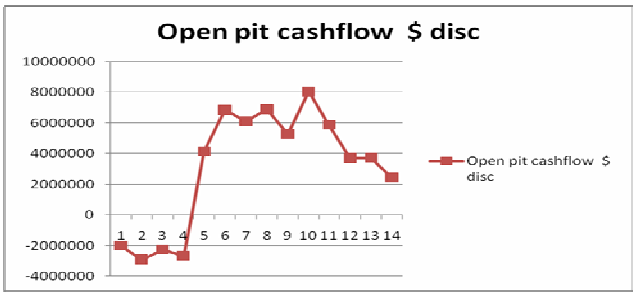

Fig. 4. *Discounted NPV for variant 2.5 Mt with 3 phase mining, mine life of 15 years, and Df=10% (SMD)*

% Variaant	*Recovery percentage for Cu in ORE in FLOT*
-10	*8.73*
0	*14.54*
10	*19.92*

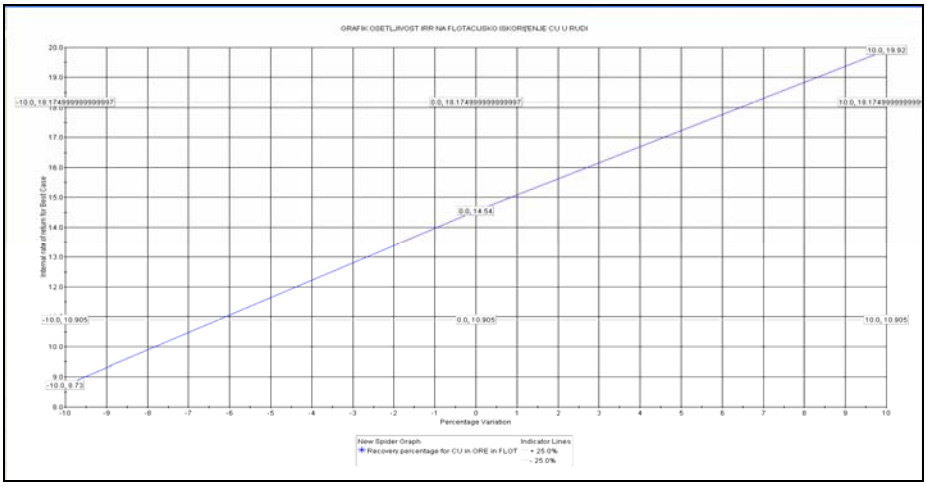

Fig. 5. *Sensitivity of IRR on flotation recovery for variant 3 F and annual productivity of 2.5 Mt*

B. *Variant 2F according to the Bussines Plann of RTB Bor, with annual productivity of 2.5 /5.5 Mt and mining at C1 and C2-2*

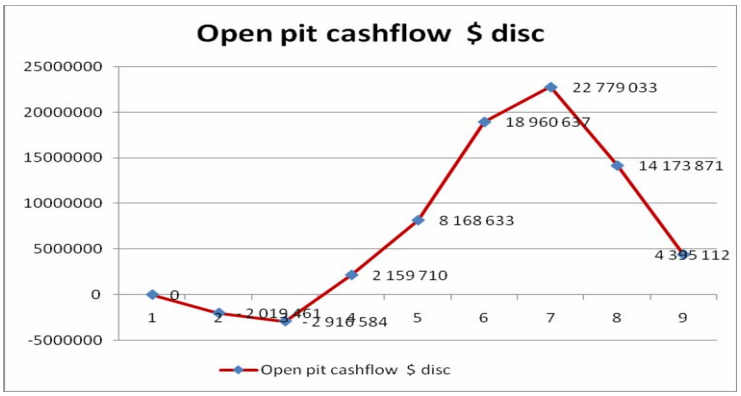

Fig. 6. *Discounted NPV for variant 2F ,Df=10%*

% Variaant	*Recovery percentage for Cu in ORE in FLOT*
-10	*6.67*
0	*14.13*
10	*20.76*

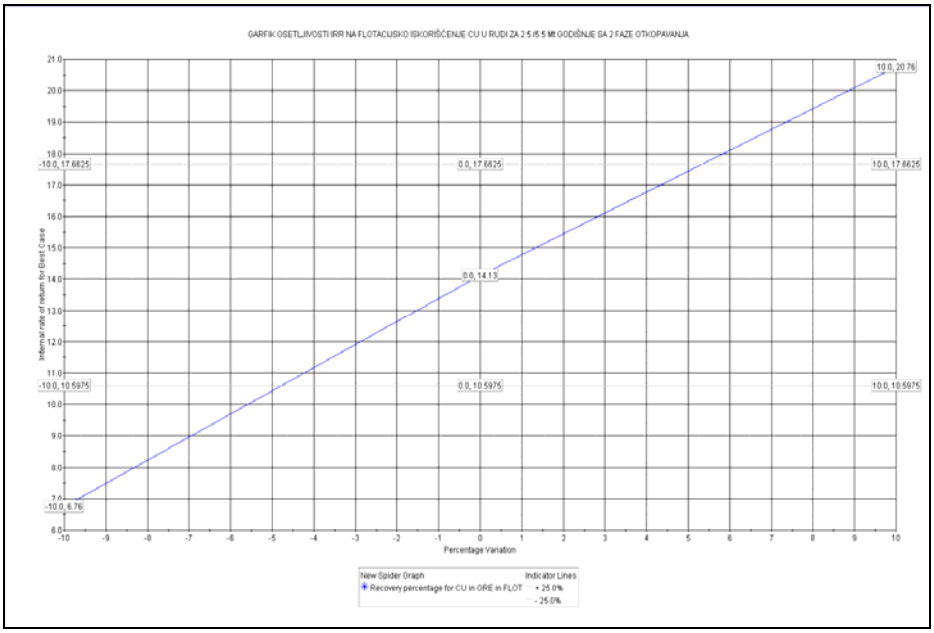

Fig. 7. *Sensitivity of IRR of the Project Cerovo on flotation recovery in the case of mining with 2 phases (push backs) and annual productivity of 2.5/5.5 Mt*

C. *Variant 3F with capacity 2.5 /5.5 Mt annually and mining at C1, C2-1 and C2-2*

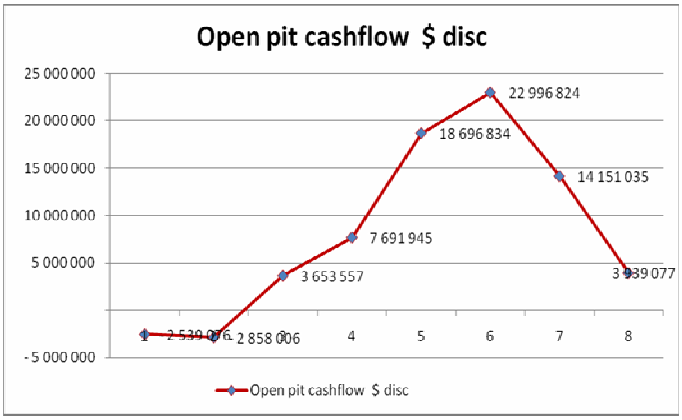

Fig. 8. *Discounted NPV for variant 3F, Df=10%*

% Variant	*Recovery percentage for Cu in ORE in FLOT*
-10	*7.45*
0	*16.05*
10	*23.48*

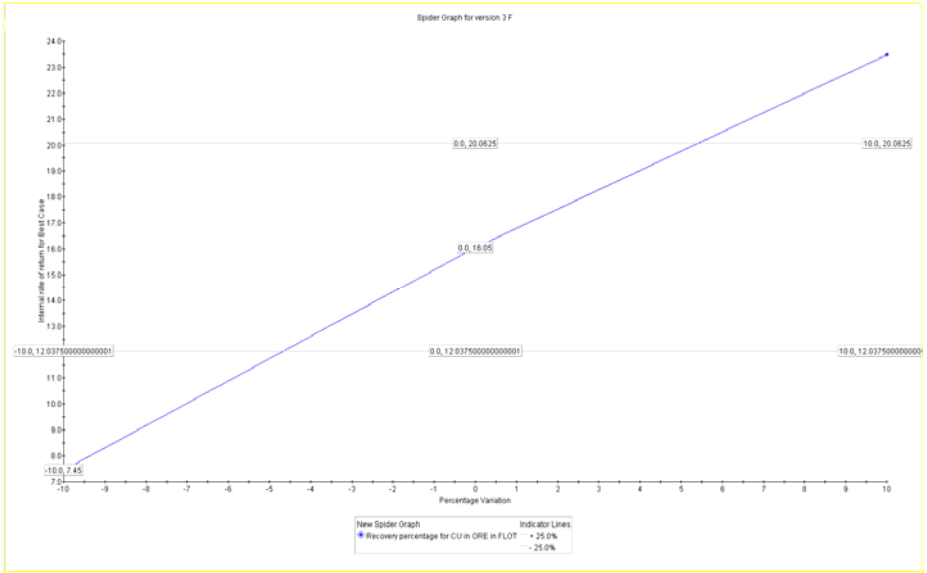

Fig. 9. *Sensitivity of IRR of the Project Cerovo on flotation recovery in the case of mining with 3 stages with capacity of 2.5/5.5 Mt annually*

CONCLUSION

Flotation recovery factor decrease of 10 %, in the mining variant "3F", results in IRR reduction to 8.6, while the change of the same factor for +10%, increases IRR 7.45, i.e. the value of change is $\Delta \pm$ IRR = 0.15;

For the variant "2F", reduction of the flotation recovery factor for 10%, reduces IRR to 7.46, while 10 % increase results in IRR increase to 6.63 ($\Delta \pm$ IRR = 0.23) meaning that the variant 2F is more sensitive to the changes in flotation recovery.

Regardless to the presented results of analysis phase mining enables higher recovery of the ore in the flotation due to the possibility of simultaneous work on several working sites faces and the possibility to provide ore composite with appropriate grade as an input to processing.

If stockpiling is not used during optimization Whittle software does not recognize significant differences in presented cases. Thus, it is necessary to perform detailed mining dynamics analysis using "*Extractive Blend Scenario*" option. This will allow the optimization of flotation metal recovery by either using stockpile or simultaneous operation of several working sites with different Cu content in ore.

REFERENCES

[1] Main Mine Design of Deposit "Cerovo – Cementation" for Annual Capacity of 2.5 x 106 t of Ore, Book I-1, Open Pit Ore Mining, Copper Institute Bor, 1991 (in Serbian);

[2] Supplementary Mine Design on Copper Ore Mining from the Deposit "Cerovo Cementacija - Kraku Bugaresku" for the Annual Capacity of 2.5 x 10^6 t per Year with Verification of Equipment for Mineral Processing, Mining and Metallurgy Institute Bor, November 2008, Authorized Designer: Z. Vaduvesković; Technical Control of the Project: Faculty of Mining and Geology (Prof. B.Kolonja), (in Serbian);

[3] Lexicon of Management, Published by: Masmedia Zagreb, 2001, Editor: Fikreta Bahtijarević-Šiber, Pere Sikavica (in Croatian);

[4] Gemcom Whittle User Manuel;

[5] Study of Combined Copper Ore Mining in the Deposit Kraku Bugaresku - Cementation and Cerovo, IRM Bor, 2009, Authorized Designer: Z. Vaduvesković (in Serbian);

[6] Business Plan for Copper Production for the Period 2011-2021, RTB Bor, Bor, 16 June 2011 (in Serbian).