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SELECTION OF AN OPTIMAL SOLUTION FOR SUPPLYING ENERGY CONSUMERS WITH COAL IN EASTERN SERBIA

IZBOR OPTIMALNOG REŠENJA ZA SNABDEVANJE ENERGETSKIH POTROŠAČA UGLJEM U ISTOČNOJ SRBIJI

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Abstract: *The analysis of perspectives of underground coal mining in Serbia has found that there were considerable possibilities for creating new mines and increasing the production. On the other hand, there are demands for coal from energy consumers. This paper analyzes possibilities and suggests optimal solutions for coal transport from underground mines to two thermal power plants in Eastern Serbia.*

Key words: *coal transport, mines, thermal power plants*

Apstrakt: *Analizom perspektiva podzemne eksploatacije uglja u Srbiji utvrđeno je da postoje značajne mogućnosti za otvaranje novih rudnika i povećanje proizvodnje. Sa druge strane postoje potrebe za ugljem od strane energetskih potrošača. U ovom radu se analiziraju mogućnosti i predlažu optimalna rešenja za transport uglja od podzemnih rudnika do dva termoenergetska postrojenja u istočnoj Srbiji.*

Ključne reči: *transport uglja, rudnici, termoenergetska postrojenja*

1 INTRODUCTION

The underground coal mining in Serbia, due to its specificities, requires certain, known consumers for a longer time period. High costs of establishing and mining for a long period encumber one ton of excavated coal and set a requirement that all costs, including transport, are minimized.

On the other hand, energy consumers (thermal power plants and heating plants) require a steady supply with energy-generating products, preferably without large price fluctuations. The history of thermal power plants and of certain heating plants in towns of Serbia indicate that the coal was often, for these purposes, transported to consumers at hundreds of kilometres away, which increased costs and raised the production costs of electric and thermal energy.

1 UVOD

Podzemna eksploatacija uglja u Srbiji, zbog svoih specifičnosti zahteva sigurne potrošače u dužem periodu. Visoki troškovi otvaranja i eksploatacije za duže vreme opterećuju tonu dobijenog uglja i postavljaju zahtev da se svi troškovi, uključujući i transport, svedu na najmanje moguće.

Sa druge strane, energetski potrošači (termoelektrane i toplane) traže stabilno snabdevanje energentima, po mogućstvu bez velikih oscilacija u cenama. Istorija termoelektrana u Srbiji i pojedinih toplana u gradovima ukazuju na to da se ugalj često, za ove potrebe, prevozio i više stotina kilometara do potrošača, uvećavajući tako troškove i poskupljujući proizvodnju električne i toplotne energije.

The concerns of a coal mine are not only to produce this energy-generating product as safely, reliably and cost-effectively as possible, but also to remain competitive in the market. It is possible, if the coal is delivered to thermal power plants and heating plants in time and with the least possible costs. The Serbian transport infrastructure is not in its best condition, but it is gradually being restored and we should expect that there will be some progress in this field too.

The objective of this paper is to suggest optimal solutions of supplying two thermal power facilities in Eastern Serbia with coal from underground mines. This was preceded by the analysis of the perspective of underground coal mining and the results thereof were used as input data.

2 CONSUMERS' DEMAND AND MINE CAPACITY

Eastern Serbia, as a region, has a need for a number of smaller heating/power plants, that is, most of towns did not completely solved the problem of supplying settlements with thermal energy. Having in mind the real situation with the source of raw materials, currently we can define with certainty the supply of thermal power plant Morava in Svilajnac and potentially thermal power/heating plant in Bor with coal from underground mining.

The thermal power plant Morava in Svilajnac of 125 MW capacity has been in operation for more than 40 years, which puts it in the category of older thermal power plants in Serbia. The plans of TENT Obrenovac, of which the power plant is the component, envisaged its general reconstruction to be in 2016.

Annual coal consumption in thermal power plant (TPP) Morava was considerably more fluctuating in past times, because this power plant had the status of a reserve. However, in the continual operation, it can be expected that annual demands for coal are about 760.000 tons with an average calorific value of 8.800 kJ/t. Based on the experience in working with such calorific values, it is realistic to expect that the specific coal consumption ranges from 1.40 to 1.45 kg/kWh.

Interes rudnika uglja, nije samo da što bezbednije, pouzdanije i ekonomičnije proizvedu ovaj energent, već da ostanu i kokurentni na tržištu. To je moguće, ako se na vreme i sa što manjim troškovima dopremi ugalj do termoelektrana i toplana. Saobraćajna infrastruktura u Srbiji nije u najboljem stanju, ali ona se postepeno obnavlja i treba očekivati da će i na tom polju doći do napretka.

Cilj ovog rada je da predloži optimalna rešenja snabdevanja dva termoenergetska objekta u istočnoj Srbiji ugljem iz podzemne eksploatacije. Tome je prethodila analiza perspektive podzemne eksploatacije uglja i rezultati ove analize su korišćeni kao ulazni podaci.

2 POTREBE POTROŠAČA I MOGUĆNOSTI RUDNIKA

Istočna Srbija, kao region, ima potrebu za više manjih toplana-energana, odnosno većina gradova nema u potpunosti rešen problem snabdevanja naselja toplotnom energijom. Imajući u vidu realnu situaciju sa sirovinskom bazom, u ovom trenutku se mogu sa sigurnošću definisati snabdevanje ugljem iz podzemne eksploatacije za termoelektranu Morava u Svilajncu i potencijalnu termoelektranu-toplanu u Boru.

Termoelektrana Morava u Svilajncu instalisane snage 125 MW je u pogonu nešto više od 40 godina, što je stavalja u red starijih termoelektrana u Srbiji. Planovima TENT iz Obrenovca, u čijem se sastavu ona nalazi, predviđena je njena generalna rekonstrukcija 2016. godine.

Godišnja potrošnja uglja u TE Morava je u prošlosti znatno više varirala, jer je ova termoelektrana imala stataus rezervne. Međutim u stalnom radu se može računati da su godišnje potrebe za ugljem oko 760.000 tona sa prosečnom toplotnom vrednošću od 8.800 kJ/t. Na osnovu iskustava u radu sa takvim toplotnim vrednostima, realno je očekivati da se specifična potrošnja uglja kreće u granicama od 1,40 do 1,45 kg/kWh.

For the needs of heating the town of Bor, it is envisaged to build a thermal power/heating plant (TETO). This plant would be built on the basis of cogeneration, that is, it would produce electric and heating energy. The designed power would be 35 MW for electric energy, and for heating energy 100 MW. In order to provide the fuel, it is necessary to deliver, on yearly basis, approx. 200,000 tons of coal with calorific value which varies from 10 to 12,000 kJ/t. It is envisaged to apply Fluidized Bed Combustion (FBC) boilers.

The envisaged coal production in mines with estimated participation of small classes in the annual production amounts to:

Za potrebe zagrevanja grada Bora planira se izgradnja termoelektrane-toplane (TETO). Ovo postrojenje bi bilo izgrađeno na bazi kogeneracije, odnosno proizvodilo bi električnu i toplotnu energiju. Projektovana snaga bi iznosila 35 MW za električnu energiju, a za toplotnu energiju 100 MW. Za obezbeđenje goriva potrebno je godišnje dopremiti cca 200.000 tona uglja sa toplotnom vrednošću koja varira od 10 do 12.000 kJ/t. Predviđena je primena kotlova sa sagorevanjem goriva u fluidiziranom sloju.

Predviđena proizvodnja uglja po rudnicima sa procenjenim učešćem sitnih klasa u godišnjoj proizvodnji iznosi:

Table 1
Tabela 1

Mine	Annual production, t	Estim. Part. small class, %	Total small class, t
SOKO	250.000	50	125.000
LUBNICA	100.000	60	60.000
REMBAS	100.000	60	60.000
ĆIRIKOVAC	1.200.000	80	960.000
MELNICA	450.000	80	360.000
Σ	2.100.000		1.565.000

Coarse coal class will have the status of commercial coal for market, i.e. for other consumers.

Krupnije klase uglja će imati status komercijalnog uglja za tržište, odnosno druge potrošače.

3 PARAMETERS OF COAL TRANSPORTATION FROM MINES TO CONSUMERS

3.1 Possible variants of coal transportation to consumers

Realistic variants of coal transportation from REMBAS mine to Svilajnac are as follows:

- Railway transportation between Resavica and TPP Morava (Variant RA),
- Truck transportation between Vodna and TPP Morava (Variant RB),

Possible variants of transportation of small class coal from Soko mine would be:

- Combined trucks-railway transportation between Soko Mine, railway station Žitkovac and TPP Morava (Variant SA),

3 PARAMETRI TRANSPORTA UGLJA OD RUDNIKA DO POTROŠAČA

3.1 Moguće varijante transporta uglja do potrošača

Realne varijante transporta uglja od rudnika REMBAS do Svilajnca su sledeće:

- Železnički transport na relaciji - Resavica-TE Morava (Varijanta RA),
- Kamionski transport Vodna-TE Morava (varijanta RB),

Moguće varijante transporta sitnih klasa uglja iz rudnika Soko bi bile:

- Kombinovani transport kamioni-železnica na relaciji rudnik Soko-žel. stanica Žitkovac-TE Morava (varijanta SA),

- Truck transportation Soko Mine-TETO Bor (Variant SB),
- Combined truck-railway transportation between Soko Mine, railway station Knjaževac and Bor (Variant SC)

The Lubnica Mine is supposed to place its small coal classes for the needs of, primarily, TETO Bor. The expected 60,000 tons a year of small classes from Lubnica Mine can be delivered to TETO Bor in two ways:

- Truck transportation from Lubnica to Bor (Variant LA).
- Combined truck-railway transportation from Lubnica to Grljani (trucks) and then by railway to Bor (Variant LB).

For the purpose of supplying the Morava Svilajnac power plant with coal from underground mine Ćirikovac, three variants of transport are possible:

- Coal transportation by railway cars from loading station Ćirikovac to TE Morava Svilajnac (Variant CA),
- Coal transportation by trucks from loading station Ćirikovac to the TE Morava (Variant CB),
- Combined truck-railway coal transportation between Ćirikovac, new loading station Drmno, railway station Stig and Svilajnac (Variant CC).

For the transportation of small coal from Melnica Mine to energy consumers there are two variants:

- Truck transportation from Melnica Mine to TE Morava (Variant MA),
- Combined truck-railway coal transportation between Melnica Mine, Kučevo railway station and TETO Bor (Variant MB).

It would be realistic to expect that the Variant MB is a reserve variant, only in case when TETO cannot provide coal from the Soko and Lubnica mines.

3.2 Elements for transport calculation

For each line of railroad the following parameters were analyzed:

- length of the rail
- condition of the rail,

- Kamionski transport rudnik Soko-TETO Bor (varijanta SB),
- Kombinovani transport kamioni-železnica na relaciji rudnik Soko-žel. stanica Knjaževac-Bor (varijanta SC)

Rudnik Lubnica svoje sitne klase uglja, prvenstveno, treba da plasira za potrebe TETO Bor. Očekivanih 60.000 tona godišnje sitnih klasa iz rudnika Lubnica se mogu dopremati do TETO Bor na dva načina:

- kamionski transport od Lubnice do Bora (varijanta LA).
- kombinovani transport kamioni – železnica od Lubnice do Grljana (kamioni) i dalje železnicom do Bora (varijanta LB),

Za potrebe snabdevanja TE Morava Svilajnac ugljem iz podzemnog rudnika Ćirikovac moguće su tri varijante transporta:

- Prevoz uglja vagonima železnicom od utovarne stanice Ćirikovac do TE Morava Svilajnac (varijanta CA),
- Transport uglja kamionima od utovarne stanice Ćirikovac do TE Morava (varijanta CB),
- Kombinovani transport uglja kamioni-železnica na relaciji Ćirikovac-nova utovarna stanica Drmno-žel. stanica Stig-Svilajnac (varijanta CC).

Za transport sitnog uglja od rudnika Melnica do energetskih potrošača moguće su dve varijante:

- kamionski transport od rudnika Melnica do TE Morava (varijanta MA),
- kombinovani transport kamioni-železnica na relaciji rudnik Melnica-žel. stanica Kučevo-TETO Bor (varijanta MB).

Realno je očekivati da varijanta MB bude rezervna varijanta, samo u slučaju kada TETO ne može da obezbedi ugalj iz rudnika Soko i Lubnica.

3.2 Elementi za proračun transporta

Za svaku trasu železničke pruge analizirani su sledeći parametri:

- dužina pruge
- stanje pruge,

- load of the rail,
- rail is (not) electrified – traction method
- loading-unloading devices
- train composition

For all lines of truck transportation the following parameters were analyzed

- description of a roadline,
- condition of the asphalt road-bed
- road configuration,
- length of a line passing through inhabited areas,
- bends on a road
- load of a road
- specificity of a roadline

The efficiency factor of a road in each line is determined as follows:

$$K_e = K_1 \times K_2 \times K_3 \times K_4 \times K_5 \qquad (1)$$

where: K_1 – coefficient of limitation due to inhabited places (0.75 – 1.0)
K_2 – coefficient of the road-bed condition (0.85 – 0.95)
K_3 – coefficient of elevations and dips of a roadline (0.7 – 1.0)
K_4 – coefficient of limitation due to bends (0.85 – 1.0)
K_5 – coefficient of the road load (0.85 – 0.95).

As a given capacity, for calculation of railway transport, monthly quantities of produced small coal were taken, while weekly quantities for truck transport.

In calculating the railway transport, compositions of itinerary trains with 25 EAS type wagons of 40 tons bearing capacity were applied. Other parameters of railway transport which are determined by calculations are as follows:

- required number of wagons for the transportation of monthly coal production,
- required number of itinerary trains in one month,
- costs of transporting one ton of coal by railway for each variant,
- yearly costs of coal transportation on the given line.

- opterećenost pruge,
- pruga (ni)je elektrificirana – način vuče
- utovarno-istovarni uređaji
- sastav voza

Za sve trase za kamionski transport su analizirani sledeći parametri

- opis trase puta,
- stanje asfaltne podloge
- konfiguracija puta,
- dužina trase koja prolazi kroz naseljena mesta,
- kivine na putu
- opterećenost puta
- specifičnost trase

Faktor efikasnosti puta na svakoj relaciji je utvrđen na sledeći način:

$$K_e = K_1 \times K_2 \times K_3 \times K_4 \times K_5 \qquad (1)$$

gde su: K_1 – koeficijent ograničenja usled naseljenih mesta (0,75 – 1,0)
K_2 – koeficijent stanja podloge (0,85 – 0,95)
K_3 – koeficijent uspona i padova trase puta (0,7 – 1.0)
K_4 – koeficijent ograničenja usled krivina (0,85 – 1,0)
K_5 – koeficijent opterećenosti puta (0,85 – 0,95).

Kao zadati kapacitet merodavan za proračun železničkog transporta uzimane su mesečne količine proizvedenog sitnog uglja, a kod kamionskog transporta su to bile nedeljne količine.

U proračunu železničkog transporta su usvojene kompozicije maršrutnih vozova sa 25 vagona tipa EAS nosivosti 40 tona. Ostali parametri železničkog transporta koji su utvrđeni proračunom su:

- potreban broj vagona za prevoz mesečne proizvodnje uglja,
- potreban broj maršrutnih vozova u toku jednog meseca,
- troškovi transporta jedne tone uglja železnicom za svaku varijantu,
- godišnji troškovi transporta uglja na razmatranoj relaciji.

For calculating the truck transport trucks of 25 tons bearing capacity are applied, and a weekly mine capacity was taken as a reference. Parameters of truck transport obtained from the calculation are as follows:

- transporting cycle of a truck,
- the number of possible cycles of a truck during a week,
- weekly capacity of one truck,
- required number of trucks in operating condition for the transportation of the weekly production,
- costs of transporting one ton of coal by trucks for each variant,
- yearly costs of coal transportation on the observed line.

After the costs analysis has been made, it is ascertained that it is more convenient to engage specialized transport companies than to form own transport units for coal transportation. In these terms, the possibilities and prices of transport services of railway and truck transporters are considered.

The quality of a transport service, regardless of who provides it, is assessed in several ways. However, indicators of transport quality, with a view to ensuring logistics to companies using raw materials or intermediate goods, can be put into four groups:

1 assurance of quality of transporting raw materials which ensure the needs of consumers,
2 preservation of properties of transported loads during the transportation and in accordance with consumers' needs,
3 Steady supply under all conditions,
4 Excluding external factors in the complex assessment of quality of transport service (politics, corruption, nepotism, etc.)

In order to increase the quality of transport service within logistics systems, it is necessary to, in compliance with the standards, periodically verify the quality of service. This can be achieved by applying survey and other methods, where users of services assess the transport work.

Za proračun kamionskog transporta usvojeni su kamioni nosivosti 25 tona, a kao merodavan je uziman nedeljni kapacitet rudnika. Parametri kamionskog transporta koji su dobijeni proračunom su:

- transportni ciklus kamiona,
- broj mogućih ciklusa jednog kamiona u toku nedelje,
- nedeljni kapacitet jednog kamiona,
- potreban broj kamiona u radnom stanju za prevoz nedeljne proizvodnje,
- troškovi transporta jedne tone uglja kamionima za svaku varijantu,
- godišnji troškovi transporta uglja na razmatranoj relaciji.

Nakon izvršene analize troškova utvrđeno je da je povoljnije angažovati specijalizovana preduzeća za transport, nego oformiti svoje transportne pogone za prevoz uglja. U tom smislu su razmatrane mogućnosti i cene transportnih usluga železnice i auto prevoznika.

Kvalitet transportne usluge, bez obzira na to ko je vrši, ocenjuje se na više načina. Međutim, pokazatelji kvaliteta transporta u cilju obezbeđenja logistike kompanija koji koriste sirovine ili repromaterijal, mogu se svrstati u četiri grupe:

1 obezbeđenje kvaliteta transporta sirovina kojim su obezbeđene potrebe potrošača,
2 očuvanje svojstava transportnih tereta u toku transporta u skladu sa potrebama potrošača,
3 Stabilnost snabdevanja u svim uslovima,
4 Isključenje spoljnih faktora pri kompleksnoj oceni kvaliteta transportne usluge (politika, korupcija, nepotizam i sl.).

Da bi se povećao kvalitet transporta u okviru logističkih sistema neophodno je, shodno standardima, periodično proveravati kvalitet usluge. To se postiže primenom anketnih i drugih metoda, gde korisnici usluga ocenjuju rad na transportu.

4 SELECTION OF THE MOST CONVENIENT VARIANT OF TRANSPORTATION FROM A MINE TO CONSUMERS

In selecting a variant of transportation, usually two analyses are made in order to obtain the best solution, as follows:

- Techno-economic analysis and
- Multi-criteria analysis

In this case there is a little bit specific situation, because, in addition to the 12 analysed variants, most of them are indifferent one to another. Therefore, the comparison here was made between two possibilities, rarely three variants.

4.1 Results of the techno-economic analysis

The Techno-economic analysis gave specific costs for each variant and necessary investments (Table 2).

Table 2
Tabela 2

Variant	Spec. costs, EUR./t	Investments, EUR.
SA	10,57	
SB_1	10,92	
SB_2	12,48	
SC	5,83	195.810
RA	1,61	
RB	5,16	
LA	4,92	
LB	3,52	
CA	2,80	1.790.000
CB	6,36	67.000
CC	5,22	315.000
MA	6,12	
MB	5,64	229.000

In techno-economic analysis the most convenient variant is the one with the minimum specific costs. For particular cases, the most suitable are the following variants:

1 REMBAS Mine – TPP Morava (Variant RA)
(railway transportation from Resavica to TPP Morava)

Transportation costs are 1.61 EUR/t and they are less than the costs in the Variant RB (truck transport), amounting to 5.16 EUR/t.

4 IZBOR NAJPOVOLJNIJE VARIJANTE TRANSPORTA OD RUDNIKA DO POTROŠAČA

Prilikom izbora neke varijante transporta, uobičajeno je da se vrše dve analize u cilju dobijanja najboljeg rešenja i to:

- tehničko-ekonomska analiza i
- višekriterijumska analiza

U ovom slučaju postoji malo specifična situacija, jer i pored analiziranih 12 varijanti, mnoge od njih su indeferentne jedna prema drugoj. Zbog toga se ovde vršilo upoređenje, najčešće, između dve mogućnosti, a retko su se poredile tri varijante.

4.1 Rezultati tehničko ekonomske analize

Tehničko-ekonomskom analizom dobijeni su specifični troškovi za svaku varijantu kao i neophodne investicije (Tabela 2).

U tehničko-ekonomskoj analizi najpovoljnija je varijanta sa najnižim specifičnim troškovima. Za konkretne slučajeve najpovoljnije su sledeće varijante:

1 Rudnik REMBAS – TE Morava (Varijanta RA)
(železnički transport od Resavice do TE Morava)

Troškovi prevoza su 1,61 EUR/t i manji su od troškova u varijanti RB (kamionski transport), koji iznose 5,16 EUR/t.

2 Ćirikovac Mine – TE Morava
(Variant CA)
(railway transportation from the load station Ćirikovac to TPP Morava)

Transportation costs are less than those in the Variant CB (6.36 EUR/t) and variant CC (5.22 EUR/t), amounting to 2.80 EUR/t.

3 Soko Mine – TETO Bor
(Variant SC)
(combined transportation by trucks from the mine to the railway station Knjaževac, reloading into wagons and then by itinerary trains to TETO Bor)

Specific costs are 5.83 EUR/t and they are less than costs per Variants SB_1 (10.92 EUR/t) and SB_2 (12.48/t)

4 Lubnica Mine – TETO Bor
(Variant LB)
(combined transportation: by trucks from the mine to the reloading station Grljan and then by railway to TETO Bor)

Transportation costs for this variant are 3.52 EUR/t and they are less than those for Variant LA (4.92 EUR/t).

5 Melnica Mine – TE Morava
Variant MA
(truck transportation from the mine to TPP Morava)

Transportation costs 6.12 EUR/t – the only variant.

6 Soko Mine – TE Morava
Variant SA
(combined transportation: by trucks from the mine to the railway station Žitkovac and further by railway to TE Morava).

The only variant with transportation costs 10.57 EUR/t.

7 Melnica Mine – TETO Bor
Variant MB
(the only variant – combined transportation: by trucks from the mine to the railway station Kučevo and then by railway to TETO Bor).

Transportation costs 5.64 EUR/t**.**

2. Rudnik Ćirikovac – TE Morava
(Varijanta CA)
(železnički transport od ut. stanice Ćirikovac do TE Morava)

Troškovi transporta su manji od varijante CB (6,36 EUR/t) i varijante CC (5,22 EUR/t) i iznose 2,80 EUR/t.

3. Rudnik Soko – TETO Bor
(Varijanta SC)
(kombinovani transport kamionima od rudnika do železničke Stanice Knjaževac, pretovar u vagone i dalje maršrutnim vozovima do TETO Bor)

Specifični troškovi su 5,83 EUR/t i manji su od troškova po varijantama SB_1 (10,92 EUR/t) i SB_2 (12,48/t)

4. Rudnik Lubnica – TETO Bor
(Varijanta LB)
(kombinovani transport: kamionima od rudnika do utovarne stanice Grljan i dalje železnicom do TETO Bor)

Troškovi prevoza za ovu varijantu su 3,52 EUR/t i manji su od troškova za varijantu LA (4,92 EUR/t).

5. Rudnik Melnica – TE Morava
Varijanta MA
(kamionski transport od rudnika do TE Morava)

Troškovi prevoza 6,12 EUR/t – jedina varijanta.

6. Rudnik Soko – TE Morava
(Varijanta SA)
(kombinovan transport: kamionima od rudnika do žel. stanice Žitkovac i dalje železnicom do TE Morava).

Jedina varijanta sa troškovima prevoza 10,57.EUR/t.

7. Rudnik Melnica – TETO Bor
(Varijanta MB)
(jedina varijanta – kombinovani transport: kamionima od rudnika do žel stanice Kučevo i odatle železnicom do TETO Bor).

Troškovi prevoza 5,64 EUR/t**.**

4.2 Application of the multi-criteria analysis

For the purpose of the multi-criteria analysis and selection of the most suitable variants of coal transportation from underground mines to energy consumers, the following criteria will be applied:

A) Specific transportation costs,
B) Amount of supplementary investments in facilities and equipment
C) Environmental protection
D) Reliability of operation during the whole year

Considering that there are a large number of variants which are indifferent one to another and that this indifference is quite explicit (visible), the Simple Additive Weight (SAW) method was applied here. This method requires creating a matrix product of matrices $\boldsymbol{\omega} = \|\omega_i\|_m$ and matrices $\mathbf{k} = \|\mathbf{k}_{ij}\|_{m,n}$, in order to obtain:

$$\mathbf{C}_i = \sum_j^n \omega_i \cdot \mathbf{k}_{ij} (\mathbf{i = 1,2,... m; j = 1,2,... n}) \qquad (2)$$

Elements of matrix ω constitute weight coefficients, whereby a special attention must be paid to that the condition is met:

$$\sum \omega_k = 1 .$$

For the particular case of external coal transportation the above mentioned criteria have the following weight coefficients:

A - 0,65, B – 0,15; C – 0,12; D – 0,8

Elements of the matrix k are quantified values of the above criteria adopted for this analysis.

The optimal solution is the element of the matrix C_i that has the maximum numerical value.

Based on the results obtained by the above method, we got the most convenient variants of coal transportation from mines to consumers.

4.2 Primena višekriterijumske analize

Za potrebe višekriterijumske analize i izbor najpovoljnijih varijanti transporta uglja od rudnika sa podzemnom eksploatacijom do energetskih potrošača, važiće sledeći kriterijumi:

A) specifični troškovi transporta,
B) visina dodatnih ulaganja u objekte i opremu
C) zaštita životne sredine
D) pouzdanost rada tokom cele godine

S obzirom na to da postoji veliki broj varijanti koje su indiferentne jedna prema drugoj i da da je ta indiferentnost jasno uočljiva, ovde je primenjena metoda jednostavnih aditivnih težina. Kod ove metode potrebno je formirati matrični proizvod matrica $\boldsymbol{\omega} = \|\omega_i\|_m$ i matrice $\mathbf{k} = \|\mathbf{k}_{ij}\|_{m,n}$, tako da bude:

$$\mathbf{C}_i = \sum_j^n \omega_i \cdot \mathbf{k}_{ij} (\mathbf{i = 1,2,... m; j = 1,2,... n}) \qquad (2)$$

Elementi matrice ω sačinjavaju težinske koeficijente, pri čemu se mora posebno voditi računa da bude ispunjen uslov:

$$\sum \omega_k = 1 .$$

Za konkretni slučaj spoljašnjeg transporta uglja navedeni kriterijumi imaju sledeće težinske koeficijente:

A - 0,65, B – 0,15; C – 0,12; D – 0,8

Elementi matrice k predstavljaju kvantifikovane vrednosti navedenih kriterijuma usvojenih za ovu analizu.

Optimalno rešenje čini elemenat matrice C_i koji ima najveću brojčanu vrednost.

Na osnovu rezultata dobijenih navedenom metodom dobijene su najpovoljnije varijante transporta uglja od rudnika do potrošača.

1. Mine REMBAS – TPP Morava	(res. 4,80)	Varijant RA
2. Mine Ćirikovac – TPP Morava	(res. 3,55)	Varijant CA
3. Mine Soko – TETO Bor	(res. 3,15)	Varijant SC
4. Mine Lubnica – TETO Bor	(res. 3,83)	Varijant LB
5. Mine Melnica – TPP Morava	(res. 3,22)	Varijant MA
6. Mine Soko – TPP Morava	(res. 1,96)	Varijant SA
7. Mine Melnica – TETO Bor	(res. 2,95)	Varijant MB

4.3 Analysis of results and possible solutions

It is typical that the both analyses gave the matching results, i.e. that the best solutions were found both using techno-economical and multi-criteria analysis. The results of technical economical and multi-criteria analysis indicate that the following solutions are optimal.

The Thermal power plant (TPP) Morava in Svilajnac can be supplied with coal from REMBAS mine, with 60,000 of small coal per annum, which would be delivered from Resavica by itinerary trains with 25 wagons of 40 ton bearing capacity. For this production, it is necessary to provide, on a monthly level, 6 trains. From the potential mine Ćirikovac, TPP Morava would obtain 340.000 tons of coal per annum, which would arrive by trains from the loading station Ćirikovac. For this production, it is necessary to provide, on yearly basis, 34 trains with 25 wagons (bearing capacity 40 tons) each. From Melnica Mine there would be 360,000 tons of coal per year, by trucks of 25 tons bearing capacity, and for this production it would be required that 19 trucks operate in two shifts a day.

Thermal power plant/heating plant Bor would be supplied with coal from the Soko Mine and Lubnica mine. From these mines total 185,000 tons a year of small coal would be delivered. In both cases the transport would be combined – by trucks then by railway. From the Soko Mine, 125,000 tons of coal per year would be transported by 25 t trucks to the newly built dump at the railway station Knjaževac. The total production could be transported with 4 trucks. At the station Knjaževac the coal would be loaded into 40 t wagons, which would be transported to TETO Bor in compositions made of 25 wagons each. It is necessary 13 of such trains per month. The coal from the Lubnica Mine would be transported by two trucks of 25 t capacity to the loading station Grljan, and then, after reloading, by wagons and composition, as in previous case, to TETO Bor. This production requires 6 trains.

4.3 Analiza rezultata i moguća rešenja

Karakteristično je da se kod obe analize rezultati poklapaju, odnosno da su najbolja rešenja nađena i tehničko-ekonomskom i višekriterijumskom analizom. Rezultati tehničko-ekonomske i višekriterijumske analize ukazuju da su optimalna sledeća rešenja.

Termoelektrana Morava u Svilajncu se može snabdevati ugljem iz rudnika REMBAS i to 60.000 tona sitnog uglja godišnje, koji bi se iz Resavice dopremao maršrutnim vozovima sa 25 vagona nosivosti po 40 tona. Mesečno je potrebno za ovu proizvodnju 6 vozova. Iz potencijalnog rudnika Ćirikovac TE Morava bi godišnje dobijala 340.000 tona uglja, koji bi stizao vozovima sa utovarne stanice Ćirikovac. Za tu proizvodnju je neophodno mesečno obezbediti 34 vozova sa po 25 vagona nosivosti 40 tona. Iz rudnika Melnica bi stizalo godišnje 360.000 tona uglja kamionima nosivosti 25 tona, a za tu proizvodnju bi bilo potrebno da dnevno u dve smene rade 19 kamiona.

Termoelektrana-toplana Bor bi se snabdevala ugljem iz rudnika Soko i rudnika Lubnica. Godišnje bi se iz ovih rudnika dopremalo ukupno185.000 tona sitnog uglja. U oba slučaja bi se transport vršio kombinovano – kamioni pa železnica. Iz rudnika Soko bi se godišnje 125.000 tona uglja transportovalo kamionima nosivosti 25 t do novoizgrađene deponije na žel. stanici Knjaževac. Celokupna proizvodnja bi se mogla transportovati sa 4 kamiona. Na stanici Knjaževac bi se ugalj utovarao u vagone nosivosti 40 t, koji bi se u kompozicijama od po 25 vagona transportovali do TETO Bor. Mesečno je potrebno 13 takvih vozova. Ugalj iz rudnika lubnica bi se prevozio sa dva kamiona nosivosti od 25 tona do utovarne stanice Grljan, a odatle, posle pretovara, prevozio vagonima i kompozicijam, kao u prethodnom slučaju, do TETO Bor. Za ovu proizvodnju je potrebno 6 vozova.

Figure 1 Schematic diagram of supplying energy consumers with coal
Slika 1 Šeme snabdevanja energetskih potrošača ugljem

⟶ truck transportation
⟶ railway transportation

⟶ kamionski transport
⟶ železnički transport

For transitional periods, when due to some reason TPP Morava cannot provide regular coal supply, certain quantities of coal may be provided from the Soko Mine, which would be transported by trucks to the loading station Žitkovac, and then further by trains to TPP Morava. A similar situation is with TETO Bor, which can be supplied also from the Melnica Mine (trucks to Kučevo and then by trains to Bor).

The residual quantities of small coal from Ćirikovac Mine would be delivered to one of the power plants of TEKO Kostolac, situated in the vicinity of the Ćirikovac Mine.

Za prelazne periode, kada iz nekog razloga TE Morava ne može obezbediti redovno snabdevanje ugljem, mogu se obezbediti određene količine uglja iz rudnika Soko, koji bi se transportovao kamionima do utovarne stanice Žitkovac i dalje vozovima do TE Morava. Slična je situacija i sa TETO Bor, koja može da se snabdeva i iz rudnika Melnica (kamioni do Kučeva i dalje vozovima do Bora).

Ostale količine sitnog uglja iz rudnika Ćirikovac bi se plasirale u jednu od termoelektrana TEKO Kostolac koje se nalaze u blizini rudnika Ćirikovac.

5 CONCLUSION

The development of coal underground mining in Serbia depends also, in addition to other factors, on ensuring regular energy consumers. The analysis of possibilities for supplying two significant thermal power plants with coal identified the optimal solution of coal transportation in order to provide them with coal on timely and reliably basis. The methodology applied is also applicable to other solutions, especially where there are a number of variants.

5 ZAKLJUČAK

Razvoj podzemne eksploatacije uglja u Srbiji zavisi, između ostalih faktora i od obezbeđivanja redovnih energetskih potrošača. Analizom mogućnosti snabdevanja ugljem dva značajna termoenergetska postrojenja utvrđena su optimalna rešenja transporta uglja u cilju njihovog blagovremenog i pouzdanog obezbeđivanja gorivom. Metodologija koja je primenjena je prihvatljiva i za druga rešenja, posebno gde postoji voše varijanti.

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