The International Journal of
TRANSPORT & LOGISTICS
Međunarodni časopis
TRANSPORT I LOGISTIKA

UDC: 622.647:622.063.6

HOW TO SELECT OPTIMUM TRANSPORTATION METHODS IN UNDERGROUND COAL MINES

NEKA PITANJA IZBORA TRANSPORTNIH SISTEMA U RUDNICIMA UGLJA

Miloš GRUJIĆ[1], Ivica RISTOVIĆ[1]
[1] *Faculty of Mining and Geology, Belgrade, Djusina 7*

Abstract: *Transportation in small underground coal mines is one of the major problems considering the inadequacy of underground coal mine roadways, small-scale outputs and long transport routs. Over the last 30 years belt conveyors has been increasingly used, suppressing the formerly dominant locomotive haulage. In the majority of cases this shift was justified but in some situations continuous belt conveyance proved not to be as viable as expected. Eventually it will be necessary to determine the optimum means of transport for each particular mine. The paper considers some of the methods that may be applied to select the most suitable system of transportation in line with the given conditions in underground mine roadways.*

Key words: *transportation, coal, optimum means of transport*

Apstrakt: *Transport uglja u malim rudnicima uglja Srbije predstavlja veliki problem s obzirom na nepodesnost prostorija, malu proizvodnju i dugačke transportne puteve. U poslednjih 30 godina došlo je do nagle ekspanzije u primeni transportera sa trakom, koji su potisli, dotle dominantan, šinski transport. U najvećem broju slučajeva ova zamena je bila opravdana, ali su ponekad, kontinualni transportni sistemi uvedeni i tamo gde nije bilo racionalno zameniti ciklični transport transporterima sa trakom. To je otvorilo pitanje neophodnosti izbora optimalnog načina transporta za svaki rudnik. U ovom radu se razmatraju neka pitanja izbora optimalnoih transportnih sistema u glavnim prostorijama rudnika uglja.*

Ključne reči: *transport uglja, optimalni načini transporta*

1 INTRODUCTION

Adopting any criteria, Serbian underground coalmines fall into the category of small-scale mines. Difficult working conditions, reduced output, limited use of machinery, high level of manual labour and other unfavourable circumstances are in fact bringing into question the viability of this type of coal mining. On the other hand there is an increasing industrial and consumer demand for a high-grade coal. This apparently contentious situation may be solved either by opening and developing new coalmines or deposit sections or with the implementation of more productive, advanced and up-to-date

1 UVOD

Rudnici uglja u Srbiji spadaju u male rudnike prema skoro svim kriterijumima za ocenu. Teški uslovi rada, mala proizvodnja, nizak stepen mehanizovanosti, veliko učešće manuelnog rada i sl., doveli su do toga da se sve više postavlja pitanje opravdanosti ovakvog načina eksploatacije. Sa druge strane, evidentna je potreba za kvalitetnijim ugljem za široku i industrijsku potrošnju. Rešenja za ovakvo stanje, između ostalog, treba tražiti u otvaranju novih rudnika uglja ili novih delova ležišta, sa savremenijim i produktivnijim tehnologijama mining technologies, which will compensate for the existing mine capacities.

Opening and development of new workings and facilities apart from shortcomings has considerable advantages with respect to the possibility of implementation of new technologies. In fact, opening and development of new mines involves fewer limitations than the reconstruction or rationalisation of the existing ones. However, in order to achieve the expected results it is necessary to opt for the best possible solution for every particular stage of coal production.

Coal hauling and hoisting is the most crucial stages of underground coal mining, particularly when it comes to economic viability. However at this stage it is not enough to solve the problems of coal conveyance, but it is necessary to deal with the transportation of workers and with the supply of raw materials to the workings. In order to be economically viable, safe, reliable and environmentally friendly the methods of transportation that are to be used in coal mines must be able to cope with all the types of load and comply with the given conditions.

The goal of this paper is to point out some crucial criteria for the selection of optimum transportation methods in the main tunnels of underground coalmines.

2 PARAMETERS SIGNIFICANT FOR THE SELECTION OF APPROPRIATE COAL TRANSPORTATION SYSTEMS

The most frequent method used to transport coal in underground workings is locomotive hauled mine cars or belt conveyors. Continuous belt conveyance is practically the best option for inclined drivages. On the other hand to determine the optimum solution for transportation in horizontal tunnels it is necessary to carry out a thorough techno-economic analysis. This analysis will be complete only if supply of materials and transportation of workers are taken into account.

Generally, the most influential factors that determine the choice of coal transportation methods are:

- the dip of the coal seam,
- the depth of underground workings,

eksploatacije, koji bi predstavljali zamenske kapacitete većine postojećih rudnika.

Otvaranje novih pogona, sa novim objektima otvaranja, ima, pored nedostataka, i značajne prednosti vezane za mogućnosti primene novih tehnologija. Prilikom otvaranja novih rudnika, revira i sl., broj ograničavajućih faktora je znatno manji nego u slučajevima kada se vrši rekonstrukcija ili racionalizacija postojećih pogona. Međutim, da bi se postigli željeni efekti, neophodno je da se za svaku fazu proizvodnje uglja izabere optimalno rešenje.

Transport u rudnicima uglja predstavlja jednu od najvažnijih faza, koja je posebno izražena kroz ekonomske efekte. U ovoj fazi se ne može govoriti samo o transportu uglja i njegovom izvozu na površinu, već je neophodno integralno rešavati probleme dopreme repromaterijala i prevoza radnika. Tehnologije transporta i transportni sistemi u rudnicima uglja moraju obuhvatiti sve vrste tereta i moraju zadovoljiti uslove da budu ekonomični, sigurni, pouzdani i da ne ugrožavaju okolinu.

Cilj ovoga rada je da ukaže na neke aspekte izbora optimalnih transportnih sistema u glavnim prostorijama rudnika uglja sa podzemnom eksploatacijom. Pri tome je pažnja posvećena transportu u horizontalnim hodnicima, bez obzira na to da li se rudnici otvaraju potkopom ili oknom.

2 NEKI PARAMETRI OD ZNAČAJA ZA IZBOR SISTEMA ZA TRANSPORT UGLJA

U glavnim transportnim prostorijama za transport uglja se najčešće primenjuju transporteri sa trakom i vagoni sa lokomotivskom vučom. Kontinualni transport trakama je, praktično, bez konkurencije u kosim prostorijama, dok je u horizontalnim hodnicima neophodno izvršiti tehničko-ekonomsku analizu u cilju nalaženja najboljih rešenja. Nijedna analiza nije potpuna ako se ne uzmu u obzir doprema repromaterijala i prevoz radnika.

Za izbor načina transporta uglja, u opštem slučaju, se mogu smatrati kao najvažniji, sledeći uticajni faktori:

- pad sloja,
- dubina eksploatacije,

- seam thickness,
- dimensions of the coalface,
- opening and development parameters,
- mining method applied,
- degree of concentration and the extent of opening and development works,
- layout of the ventilation system,
- the content of gas,
- physical and mechanical properties of the material transported,
- number of working horizons etc.

The transportation through main horizontal tunnels is defined by their cross-section, hauling lengths, change of direction, the intensity of material supply etc.

At first sight the cross-section of the hauling levels appears more favourable for the belt conveyors. However, the need for additional facilities to provide the supply of materials and larger cross-sections for their installation diminishes substantially the advantages of continuous belt conveyance.

Frequent change of direction also poses a disadvantage for the continuous belt conveyance since this requires a larger number of conveying units, which automatically means more transfer points. This drawback can be sorted out or reduced to minimum when new development drifts are designed. Besides, new generations of belt conveyors are able to cope with sharp bends, which are frequent in main development drifts.

The rate of coal flow is also one of the significant parameters when opting for the most suitable method of transportation. This rate is in fact the quantity of coal delivered from the faces in a unit of time. As a random value it is defined by mathematical expectancy and by the coefficient of variation. The random character of the coal flow rate imposes the need for determining the overall throughput of the system in order to size and choose properly the transportation system and all its units.

Every unit of the transportation system (means of transport, storage bins etc.) is technologically defined by its capacity or output. Namely, the throughput of a system represents the product of its technical capacity and the probability of its full volume. By definition, the technical possibilities, structural parameters and reliability of a particular conveying or hauling unit

- debljina sloja,
- dimenzije otkopnog polja,
- parametri otvaranja i pripreme,
- tehnologija otkopavanja,
- stepen koncentracije i intenziteta pripremnih i otkopnih radova,
- šema provetravanja,
- gasonosnost,
- fizičko-mehanička svojstva materijala koji se transportuje,
- broj radnih horizonata itd.

Za transport u glavnim horizontalnim prostorijama, su najvažniji profili prostorija, dužine transporta, promene pravca prostorija, intenzitet dotoka materijala i dr.

Poprečni preseci (profili) transportnih prostorija, na prvi pogled favorizuju transportere sa trakom pri izboru transportnog sistema. Međutim, potrebe za posebnim postrojenjima za dopremu repromaterijala i povećanim profilima prostorija radi njihovog postavljanja, znatno smanjuju prednosti kontinualnih transportnih sistema.

Česte promene pravca prostorija mogu predstavljati nepovoljnost za primenu kontinualnih transportnih sistema zbog potreba većeg broja transportnih jedinica i pojave većeg broja presipnih mesta. Ovaj nedostatak se, prilikom projektovanja novih prostorija otvaranja, može, uglavnom, izbeći ili svesti na minimum. Pored toga, nove generacije transportera sa trakom mogu savladavati i krivine većeg radijusa, kakve se i najčešće sreću u glavnim prostorijama otvaranja.

Intenzitet dotoka uglja na glavni transportni sistem je veoma važan parametar prilikom izbora transportnog sistema i predstavlja količinu uglja dobijenu sa otkopa u jedinici vremena. Kao slučajna veličina definisan je matematičkim očekivanjem i koeficijentom varijacije. Slučajni karakter dotoka uglja na transportni sistem nameće potrebu utvrđivanja propusne sposobnosti sistema, u cilju pravilnog dimenzionisanja i izbora elemenata transportnog sistema.

Svaki element transportnog sistema (transportno sredstvo, bunker i sl.) definisan je u tehnološkom smislu svojim kapacitetom ili prozvodnošću. Proizvod tehničkog kapaciteta i verovatnoće da se taj kapacitet ostvari određuje propusnu sposobnost. Po definiciji propusna sposobnost transportnog sistema određena je tehničkim determine the throughput of a transportation system.

Reliability is one of the parameters that is very difficult to determine since it is highly complicated to register the number of standstills, to establish their causes, the time in which the operation is resumed etc. In such cases it is necessary to adopt mean values for these parameters. The parameter that determines the course of the standstill (λ) is defined as the reciprocal value of the mean standstill duration. The parameter that determines the course of resumption of operations (μ) is defined as the reciprocal value of the mean duration of uninterrupted operation of the system.

Every production and transportation process has alternating periods of uninterrupted operation and standstill. Figure 1 presents the diagram that shows possible standstill of the system where denotes the periods of operation and denotes the periods of standstill.

mogućnostima i konstruktivnim parametrima, kao i pouzdanošću transportnih jedinica.

Prilikom izbora novih transportnih sistema javlja se problem određivanja parametara pouzdanosti, s obzirom na to da nije moguće pratiti podatke o broju otkaza, njihovim uzrocima, trajanju zastoja, trajanju rada između zastoja i sl. Zbog toga se u takvim slučajevima pribegava usvajanju srednjih veličina parametara tokova zastoja i obnavljanja sistema sa sličnim karakteristikama. Parametar toka zastoja (L) je definisan kao recipročna vrednost srednjeg vremena zastoja, a parametar toka obnavljanja (M) kao recipročna vrednost srednjeg trajanja neprekidnog rada sistema.

U svakom proizvodnom, a samim tim i transportnom sistemu, smenjuju se periodi neprekidnog rada sa periodima zastoja. Na slici 1 data je šema mogućih realizacija zastoja sistema, gde je sa obeležen rad transportnog sistema, a sa zastoj.

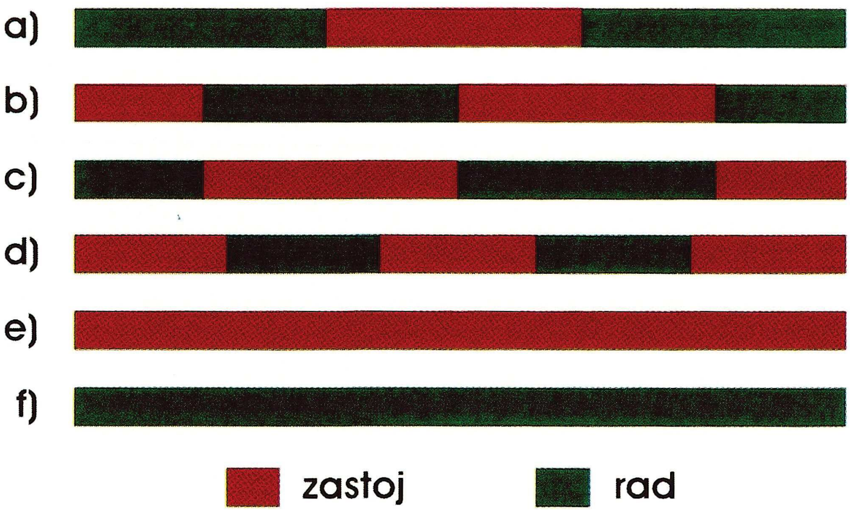

Figure 1 Diagram showing the periods of transportation standstill
slika 1 Šema realizacije zastoja transportnog sistema

If we denote with n_r the mean number of periods of uninterrupted transportation process and with n_z the mean number of periods of operation then the diagram presented in the Figure 1 shows that the ratio between the mean number of periods of standstill and the mean number of periods of uniterrupted operation may be:

$$\alpha_t = \frac{n_z}{n_r} > 1;\ \alpha_t = 1;\ \alpha_t < 1. \qquad (1)$$

Ako sa n_r obeležimo srednji broj perioda neprekidnog rada transportnog sistema, a sa n_z srednji broj perioda čistog rada, onda se sa šeme na slici 1 uočava da odnos srednjeg broja perioda zastoja i srednjeg broja perioda neprekidnog rada može biti:

$$\alpha_t = \frac{n_z}{n_r} > 1;\ \alpha_t = 1;\ \alpha_t < 1. \qquad (1)$$

If the parameters that determine the course of standstill, the course of resumption and the coefficient α_t are known then the mean number of standstills for the time t will be as follows:

$$n_z = \frac{t \cdot r \cdot \mu \cdot \alpha_t}{\mu + \alpha \cdot \alpha_z} \qquad (2)$$

Time efficiency ratio for the time t may be expressed through the mean number of standstills:

$$k_b = 1 - \frac{n_z}{\mu \cdot t} = \frac{n_z}{\lambda \cdot t \cdot \alpha_z}, \qquad (3)$$

or

$$k_b = 1 - \frac{\lambda \cdot \alpha_t}{\mu + \lambda \cdot \alpha_t}. \qquad (4)$$

In order to define the transportation system in detail it is substantial to determine precisely the parameters α and μ, which will enable the determination of the remaining reliability parameters. The results obtained for each transportation system are displayed in tables and are arranged according to the type of transport and according to the characteristics of underground transportation roadways.

The most complete information about system throughput may be obtained if the calculation time efficiency ratio (k_{br}) is applied as the reliability parameter, which also introduces the machine time ratio k_m (which represents the ratio of the aggregate duration of periods of uninterrupted work and the time t.)

$$k_{br} = \frac{k_m}{1 - k_b + k_m}. \qquad (5)$$

Applying the previously determined mathematical expectancy (mean value), the coal flow rate $M(q_t)$ and coefficient of variation δ, it is possible to calculate with a high level of accuracy the overall throughput of the transportation system.

$$P_{rt} = M(q_z) \cdot k_{br} \cdot (1 + z \cdot \delta), \qquad (6)$$

Srednji broj zastoja za neko vreme t, ako se poznaju parametar toka zastoja, parametar toka obnavljanja i koeficijent α_t, biće:

$$n_z = \frac{t \cdot r \cdot \mu \cdot \alpha_t}{\mu + \alpha \cdot \alpha_z}. \qquad (2)$$

Vremenski koeficijent iskorišćenja za neko vreme t se može izraziti preko srednjeg broja zastoja:

$$k_b = 1 - \frac{n_z}{\mu \cdot t} = \frac{n_z}{\lambda \cdot t \cdot \alpha_z}, \qquad (3)$$

ili

$$k_b = 1 - \frac{\lambda \cdot \alpha_t}{\mu + \lambda \cdot \alpha_t}. \qquad (4)$$

Pravilno određivanje parametara α i μ i preko njih nalaženje ostalih parametara pouzdanosti, je veoma važan deo posla pri definisanju transportnog sistema. Rezultati za svaki transportni sistem se prikazuju tablično i pri tome se razvrstavaju prema vrsti transporta i prema podzemnim prostorijama kroz koje se vrši transport.

Najpotpuniji podaci o propusnoj sposobnosti sistema se dobijaju kada se kao parametar pouzdanosti primeni koeficijent računskog iskorišćenja k_{br}. On se dobija kada se poznaje koeficijent mašinskog vremena svakog elementa sistema k_m, a koji predstavlja odnos ukupnog vremena neprekidnog rada i operativnog vremena rada elementa sistema t:

$$k_{br} = \frac{k_m}{1 - k_b + k_m}. \qquad (5)$$

Uz ranije utvrđeno matematičko očekivanje (srednju vrednost) intenziteta dotoka uglja $M(q_t)$ i koeficijent varijacije δ, moguće je, sa visokim stepenom tačnosti definisati računsku propusnu sposobnost transportnog sistema:

$$P_{rt} = M(q_z) \cdot k_{br} \cdot (1 + z \cdot \delta), \qquad (6)$$

where the parameter z corresponds to the probability of the coefficient of variation.

If the transportation units are mutually connected by means of bins the relationship between throughput parameters is considerably changed. On the assumption that a large bin (of indefinite capacity) is installed in the main haulage level and the mathematical expectancy of the coal flow rate is constant, then the coefficient of variation will be zero, provided that this bin is never completely unloaded. In this case the machine time ratio is increased to the maximum and the irregularity of coal flow rate is eliminated.

3 ANALYSIS OF THE METHOD PROPOSED FOR THE SELECTION OF OPTIMUM TRANSPORTATION IN UNDERGROUND COAL MINES

In underground coal mines the main haulage and transportation roadways represent capital projects and the depreciation period is frequently equal to the lifetime of relevant mines or mining districts. These roadways mainly consist of horizontal tunnels, headings and other forms of drivages, along which apart from coal it is also necessary to transport materials and workers. The inclination of roadways enables both locomotive haulage and belt conveyance, which offers a series of possibilities when opting for the best solution.

The Department of Mine Haulage and Hoisting at the Faculty of Mining and Geology in Belgrade has developed a model and corresponding software (ITRANSIS) that is successfully applied with a view of selecting the most favourable method of transportation in horizontal coal-mine roadways. The fist version of this programme has been issued in 1983 and the new improved and advanced versions were released in 1992 and in 2003. The object of these programmes is to minimise specific costs following the stringent limitations that result from the technical analysis of possible options. The function reads as follows:

$$c_g = \frac{\sum I_m \cdot \alpha_m \cdot e_m \cdot \lambda_m + C_{io} + E_g}{Q_{god}}, \rightarrow \min \qquad (7)$$

gde je z parametar koji odgovara verovatnoći sa kojom se određuje koeficijent varijacije.

U slučajevima kada transportna sredstva nisu direktno povezana, već u punktovima veze postoje bunkeri, dolazi do značajnih izmena u odnosima parametara propusne sposobnosti. Ako se pođe od pretpostavke da u glavnom transportnom hodniku postoje bunkeri velike (neograničene) zapremine i da je matematičko očekivanje dotoka uglja konstantno, onda će koeficijent varijacije biti jednak nuli, pod uslovom da se taj bunker nikada ne prazni u potpunosti. U tom slučaju koeficijent mašinskog vremena se maksimalno povećava i postiže se eliminacija neravnomernosti dotoka uglja.

3 ANALIZA MOGUĆNOSTI IZBORA TRANSPORTNOG SISTEMA U RUDNICIMA UGLJA

U rudnicima uglja sa podzemnom eksploatacijom glavne transportne prostorije se izrađuju kao kapitalni objekti, čiji je vek amortizacije često izjednačen sa vekom rudnika ili revira. To su uglavnom horizontalne prostorije po kojima se, pored transporta uglja, doprema repromaterijal i prevoze radnici. Po prostorijama ovakvog nagiba moguća je primena lokomotivskog transporta i transporta trakama, što omogućava da se iscrpnom tehničko-ekonomskom analizom izabere optimalni transportni sistem

Na Katedri za transport i izvoz Rudarsko-geološkog fakulteta u Beogradu izrađen je model za izbor optimalnog transportnog sistema u horizontalnim prostorijama rudnika uglja i odgovarajući softver (ITRANSIS). Prva verzija ovog programa je urađena još 1983. a dopune i inoviranja su izvršeni 1992. i 2003. godine. Funkcija cilja u ovom modelu su minimalni specifični troškovi, uz veoma stroga ograničenja koja proizilaze iz tehničke analize mogućih varijanti, i ima sledeći oblik:

$$c_g = \frac{\sum I_m \cdot \alpha_m \cdot e_m \cdot \lambda_m + C_{io} + E_g}{Q_{god}}, \rightarrow \min \qquad (7)$$

where: I_m - initial or launching investments of projects and transport equipment,
α_m - annuity rate,
e_m - rate of gradual replacement of fixed assets,
λ_m - liquidity ratio,
C_{io} - annual capital expenditures on projects and equipment maint
E_g - aggregate annual operating costs relating to transportation, which include energy costs, upkeep, salaries and wages of the employees and other material costs,
Q_{god} - annual coal output to be transported by the system.

The model analyses both system with or without bins. Particular attention is paid to the reliability factor in terms of determining the throughput of the system.

By applying this model and the relevant software it was possible to analyse 10.200 possible transportation methods through the main hauling and conveying levels. Several transportation lengths are considered ranging from 500 to 5000 m. Annual outputs range from 200.000 to 1.200.000 t. The solutions mainly referred to continuous systems with or without storage bins and to locomotive haulage powered either by battery or trolley cable reel also with or without bins.

The supply of materials and transport of workers in systems with continuous belt conveyance is organised via monorail. In locomotive haulage systems the workers and material are transported via mine cars that pass through main haulage levels.

After analysing all the proposed solutions it is possible to state that the specific costs reach the maximum value at the lowest coal output (200.000 t). This is closely connected with the effective use of transport capacities. For each analysed annual output it is possible to set out precisely the boundary lengths within which either belt conveyance or locomotive haulage is more appropriate. The diagram (Figure 2) shows the change of specific costs in terms of transportation lengths for each optimal solution. (Only the largest and the smallest annual outputs have been considered.)

gde su: I_m - početna ulaganja u objekte i opremu za transport,
α_m – godišnja stopa anuiteta,
e_m – koeficijent etapnosti zamene osnovnih sredstava,
λ_m – koeficijent likvidacione vrednosti,
C_{io}- godišnji troškovi investicionog održavanja opreme i objekata,
E_g – ukupni godišnji troškovi rada na transportu koji obuhvataju troškove energije, tekućeg održavanja, nadoknadu zaposlenima i ostale materijalne troškove,
Q_{god} – godišnja proizvodnja uglja koja se transportuje tim sistemom.

U modelu se analiziraju sistemi sa bunkerima i bez njih, a posebno je posvećena pažnja uticaju pouzdanosti sistema pri definisanju propusne sposobnosti.

Na osnovu ovog modela i uz pomoć navedenog softvera, izvršene su analize 10.200 mogućih varijanti transporta kroz glavne transportne prostorije. Pri tome su obrađivane transportne dužine od 500 do 5000 m, a godišnje proizvodnje su se kretale od 200.000 do 1.200.000 t. Varijantna rešenja su se odnosila na kontinualne sisteme sa i bez bunkera i šinski transport sa akumulatorskim i kontaktnim lokomotivama, takođe sa i bez bunkera.

Doprema repromaterijala i prevoz ljudi kod primene transportera sa trakom su organizovani pomoću jednošinskih visećih žičara, a kod primene lokomotivskog transporta repromaterijal i radnici se prevoze odgovarajućim vagonima po koloseku u glavnim transprtnim prostorijama.

Analizom dobijenih optimalnih rešenja može se konstatovati da su najveći specifični troškovi za najmanju proizvodnju uglja (200.000 t), što je usko povezano sa iskorišćenjem transportnih kapaciteta. Za svaku analiziranu godišnju proizvodnju postoje granične dužine do kojih je optimalna primena sistema sa transportnim trakama, a od kojih je povoljnija primena lokomotivskog transporta. Na dijagramu (slika 2) su prikazane promene specifičnih troškova u zavisnosti od dužine transporta za svako optimalno rešenje. (Prikazane su samo najmanje i najveće analizirane godišnje proizvodnje).

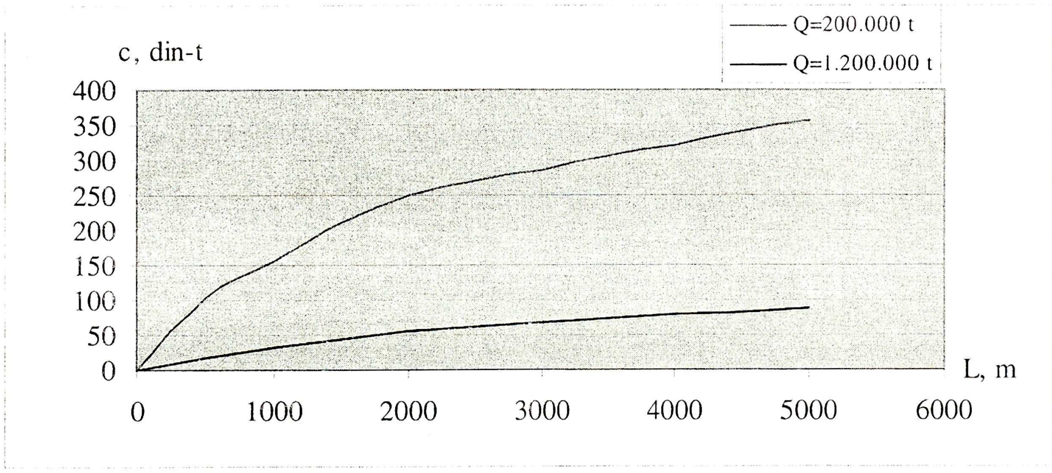

Figure 2 Diagram showing the lowest transportation costs
slika 2 Dijagram najnižih troškova transporta

The following expressions illustrate the minimum transportation costs contingency:

for 200.000-t output:

$$y = -e\text{-}0.5x^2 + 0.135x + 25.643 \quad (8)$$

for 1.200.000-t output:

$$y = -3e\text{-}0.6x^2 + 0.0304x + 2.9441 \quad (9)$$

Analysing the results obtained it may be noted that boundary transportation lengths that delimit and condition the method of transportation range from 1600 to 2100 m. From the previous it is possible to draw the following conclusion; belt conveyance is the best method of transportation in horizontal passageways that are up to 1600 m long and for passages over 2100 m in length it is more appropriate and cost-effective to use locomotive haulage, regardless of the output. Transport optimisation for the boundary zone that range from 1600 to 2100 m should be carried out through techno-economic analysis.

4 CONCLUSION

The selection of optimum transportation methods in underground coal mines requires detailed analyses of all influential factors. Coal production costs in underground mining are high as it is and therefore it is necessary to search for the most suitable and cost-effective solutions for each production stage, i.e. to minimise specific

Zavisnost minimalnih troškova transporta se može prikazati i kroz sledeće izraze:

za proizvodnju od 200.000 t:

$$y = -e\text{-}0.5x^2 + 0.135x + 25.643 \quad (8)$$

za proizvodnju od 1.200.000 t:

$$y = -3e\text{-}0.6x^2 + 0.0304x + 2.9441 \quad (9)$$

Kada se analiziraju rezultati izbora optimalnih transportnih sistema u novim rudnicima, može se uočiti da se oblast u kojoj se nalaze granične dužine kreće od 1600 do 2100 m. Iz toga treba izvući opšti zaključak da se kod projektovanja transporta u glavnim horizontalnim prostorijama može uzeti da je do 1600 m optimalna primena transportera sa trakom, a preko 2100 m lokomotivskog transporta, bez obzira na obim proizvodnje. U dijapazonu od 1600 do 2100 m (zoni optimizacije) potrebno je tehničko-ekonomskom analizom tražiti optimalno rešenje.

4 ZAKLJUČAK

Izbor optimalnog transportnog sistema u rudnicima uglja zahteva analizu uticajnih parametara ove kompleksne problematike. Troškovi proizvodnje uglja u podzemnoj eksploataciji su, već sami po sebi visoki, tako da se u svim fazama treba bazirati na optimalno rešenje, odnosno izvršiti minimizaciju specifičnih troškova. Kod costs. Designing of new transportation systems in newly opened development drifts requires impartial, objective and detailed analyses of all possible options considering all their advantages and drawbacks. The model and software presented and suggested herein supplies the decision-maker with enough grounds as to opt for the best possible solutions among several thousand potential alternatives.

projektovanja novih transportnih sistema, u novim horizontalnim prostorijama otvaranja, neophodno je izvršiti analizu svih mogućih varijanti, bez predrasuda o prednostima i nedostacima pojedinih rešenja. Predloženi model i softver omogućavaju donosiocu odluke da se opredeli za najpovoljniju od više hiljada mogućih varijanti.

REFERENCES / LITERATURA

[1] *Grujić, M.: Izbor transportnih sistema u rudnicima uglja. RGF Beograd, p.p. 139, Beograd, 1992.*
[2] *Grujić, M., Ristović, I.: To What Extent to Number of Conveyors Affects the Operating Efficiency of Haulage Szstems in Coal Mines. Mine Planing and Equipment Selection 2004, Balkema, p.p. 553-556, Roterdam, 2004.*
[3] *Ponamarenko, V. A.: Systemi podzemnogo transporta na ugolnyh shahtah. Nedra, p.p. 323, Moskow, 1977.*

Reviewal / Recenzija: prof. dr Božo Kolonja