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

UDC:65.012.34

ENVIRONMENTAL LOGISTICS OF TRANSPORTING OPENCAST MINERALS

EKOLOŠKA LOGISTIKA KOD TRANSPORTA MINERALNIH SIROVINA SA POVRŠINSKIH KOPOVA

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Abstract: *It's shown that environmental logistics of transporting opencast minerals reflects basic dependences of influencing environment during opencast mining by delivering minerals from working faces to loading points and subsequent moving mineral production to a consumer. Consequently, at this case basic logistic operation is transporting and basic environmental component undergoing negative influence is atmosphere. The problem of evaluating mineral demand at the logistical net and periodicity of delivering minerals to load points was solved. Theoretical principal about acting two contrary tendencies was proved. The first tendency is increasing one transport operation cost by increasing quantity transport cycles at the expense of increasing diesel oil cost and paying polluting atmosphere. The second tendency is decreasing exploitation costs per transport operation at the expense of increasing mineral operating profit.*

Key words: *environmental logistics, logistical net, logistical function, mineral demand, mathematical model, motor transport, minerals, open pit.*

Apstrakt: *Poznato je da ekološka logistika transporta ruda iz površinskih kopova odražava osnovne zavisnosti uticaja na okolinu prilikom površinske eksploatacije putem dopreme ruda iz kopova do mesta utovara a zatim premeštanja rudnih proizvoda do potrošača. Shodno tome, osnovna logistička operacijacije transport a osnovna komponenta sredine koja je izložena negativnom uticaju jeste atmosfera. Rešen je problem procene potrebe za rudama na nivou logističke mreže i učestalosti dopreme ruda do mesta utovara. Dokazan je teoretski princip o delovanju dve suprotne tendencije. Prva tendencija je povećanje jednog operativnog troška transporta putem povećanja broja ciklusa transporta na račun sve veće cene dizel ulja i plaćanja takse na zagađenje atmosfere. Druga tendencija je smanjivanje troškova ekspolatacije po transportnoj operaciji na račun povećanja operativnog profita ruda.*

Ključne reči: *ekološka logistika, logistička mreža, logistička funkcija, potreba za rudama, matematički model, motorni transport, rude, površinski kop.*

1 INTRODUCTION

Environmental logistics of transporting opencast minerals reflects basic dependences of influencing environment during opencast mining by delivering minerals from working faces to

1 UVOD

Ekološka logistika transporta ruda iz površinskih kopova odražava osnovne zavisnosti uticaja na okolinu prilikom površinske eksploatacije putem dopreme ruda iz kopova do mesta utovara a zatim loading points and subsequent moving mineral production to a consumer. Apparently, that motor transport used at open pits and coal open mines is most interesting for environmental evaluating. Consequently, at this case basic logistic operation is transporting and basic environmental component undergoing negative influence is atmosphere. Mineral and initial treatment products transport flows will be characterized by different environmental-logistical costs. The environmental-logistical costs are conditioned of using diesel oil cost and paying polluting atmosphere.

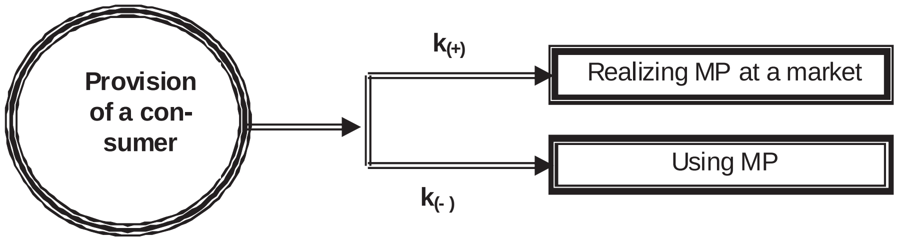
premeštanja rudnih proizvoda do potrošača. Jasno je da je za ekološku procenu najviše od interesa transport motornim vozilima koji se koristi u površinskim kopovima i površinskim rudnicima uglja. Shodno tome, osnovni rad logistike u ovom slučaju je transport a osnovna komponenta sredine koja je izložena negativnom uticaju jeste atmosfera. Transportni tokovi mineralnih proizvoda i proizvoda u početnoj fazi obrade biće određeni različitim ekološko-logističkim troškovima. Ekološko-logistički troškovi su uslovljeni troškom korišćenja dizel-ulja i plaćanjem takse za zagađenje atmosfere.

2 PROGNOSTIC EVALUATING MINERAL DEMAND

A problem is prognostic evaluating mineral demand at the logistical net of deliveries. Analyzing statistical data on mineral demand conjuncture shows that the demand, as a rule, increases with the course of time. It increases initially slowly, then quickly and becomes slower during saturation process. Consequently, increasing demand velocity is proportional of providing and impregnating of a market by marketable products (MP). The calculating scheme of forming mineral providing dynamic is shown in Picture 1.

2 PROGNOZA PROCENE POTRAŽNJE ZA MINRELNIM SIROVINAMA

Problem predstavlja prognoza procene potražnje za rudama na nivou logističke mreže doprema. Analiziranje statističkih podataka o potražnji za mineralima pokazuje da se potražnja, po pravilu, povećava tokom vremena. Povećava se najpre polako, zatim brzo i učestalost postaje sporija tokom procesa zasićenja. Prema tome, brzina povećavanja potražnje je proporcionalna snabdevanju i zadovoljavanju tržišta proizvodima za prodaju (PP). Na slici 1 prikazana je šema izračunavanja stvaranja dinamike snabdevanja rudama.



Picture 1 The calculating scheme of forming mineral providing dynamic
slika 1 Šema izračunavanja stvaranja dinamike snabdevanja mineralnim sirovinama

Formally, a model of providing dynamic for the marketable products has to describe by velocities two inverse processes. The first process is increasing mineral neediness and the second process is increasing mineral provision at the expense of their selling at the market. The velocities of increasing mineral neediness and increasing mineral provision at the expense of their selling at the market processes by competing material and energetic resources have these forms:

Formalno, model za obezbeđivanje dinamike za proizvode za prodaju mora da opiše, po brzini, dva inverzna procesa. Prvi proces je povećanje potrebe za rudama a drugi proces je povećanje snabdevanja rudama na račun njihove prodaje na tržištu. Brzina procesa kojom se povećava potreba za mineralima i brzina kojom se povećava snabdevanje mineralima na račun njihove prodaje na tržištu pomoću konkurentnog materijala i energetskih resursa, možemo izraziti u sledećem obliku:

$$W_{(+)} = \frac{dY}{dt} = k_{(+)}(Y_H - Y)Y, \qquad (1)$$

$$W_{(-)} = \frac{dY}{dt} = k_{(-)}Y^2, \qquad (2)$$

where: $W_{(+)}$, $W_{(-)}$ - the velocities of increasing mineral neediness and increasing mineral provision at the expense of their selling at the market processes conformably;
Y - mineral provision representative of market subjects having the minerals part;
Y_H - initial value of the mineral provision;
$k_{(+)}$, $k_{(-)}$ - constants of velocities for processes increasing mineral neediness and increasing mineral provision.

There is a dynamic equilibrium at the market, which realizing like stationary condition of the mineral demand. Then follow relation is correct: $W_{(+)} = W_{(-)}$. It makes possible to calculate of limiting mineral provision value (Y_∞) by follow formula:

$$Y_\infty = \frac{k_{(+)}}{k_{(+)} + k_{(-)}} Y_H. \qquad (3)$$

Mathematical model of market production provision by competing material and energetic resources with subject to relations (1) and (2) can be written at follow form:

$$\frac{dY}{dt} = (\varepsilon - \beta Y)Y, \qquad (4)$$

where $Y\big|_{t=0} = Y_H = \text{const}$; $\varepsilon = \beta Y_\infty$.

A solution of equation (4) has follow form:

$$Y(t) = \frac{Y_\infty}{\left[1 + \left(\frac{Y_\infty}{Y_H} - 1\right)\exp(-\varepsilon t)\right]}. \qquad (5)$$

Mathematical model (5) parameters values can be evaluated by minimization of least-squares modify criteria (F). The least-squares modify criteria has follow form:

$$W_{(+)} = \frac{dY}{dt} = k_{(+)}(Y_H - Y)Y, \qquad (1)$$

$$W_{(-)} = \frac{dY}{dt} = k_{(-)}Y^2, \qquad (2)$$

gde su: $W_{(+)}$, $W_{(-)}$ - brzina povećanja potrebe za rudama odnosno povećanja snabdevanja rudama na račun njihove prodaje na tržištu;
Y - snabdevanje rudama, tipičnim za tržišne subjekte koji sa mineralnim delom;
Y_H - početna vrednost snabdevanja rudama;
$k_{(+)}$, $k_{(-)}$ - konstante brzina za procese povećanja potrebe za rudama odnosno povećanja snabdevanja rudama.

Na tržištu postoji dinamička ravnoteža, koja se ostvaruje kao stalan uslov potražnje za rudama. Zatim sledi jednakost: $W_{(+)} = W_{(-)}$. Ovo omogućava da se izračuna granična vrednost snabdevanja rudama (Y_∞) putem sledeće formule:

$$Y_\infty = \frac{k_{(+)}}{k_{(+)} + k_{(-)}} Y_H. \qquad (3)$$

Matematički model snabdevanja tržišta proizvodima pomoću konkuretnih materijala i energetskih resursa u zavisnosti od odnosa (1) i (2) može se izraziti u sledećem obliku:

$$\frac{dY}{dt} = (\varepsilon - \beta Y)Y, \qquad (4)$$

gde je $Y\big|_{t=0} = Y_H = \text{const}$; $\varepsilon = \beta Y_\infty$.

Rešenje jednačine (4) ima sledeći oblik:

$$Y(t) = \frac{Y_\infty}{\left[1 + \left(\frac{Y_\infty}{Y_H} - 1\right)\exp(-\varepsilon t)\right]}. \qquad (5)$$

Vrednosti parametara matematičkog modela (5) mogu se proceniti putem metode najmanjih kvadrata (F). Metoda najmanjih kvadrata ima sledeći oblik:

$$F=\sum_{k=1}^{N}\left\{Y_k-\frac{Y_\infty}{\left[1+\left(\frac{Y_\infty}{Y_H}-1\right)\exp(-\varepsilon t_k)\right]}\right\}^2\lambda_k\ , \qquad (6)$$

where $\lambda_k=\sigma_k^{-2}$;

σ_k - root-mean-square deviation.

Mathematical models parameters must correspond with optimization condition, which agreeing a minimum of the least-squares modify criteria:

$$F\Rightarrow\min_{\{Y_\infty;\beta\}}. \qquad (7)$$

Let's write the differential equation (4) at a difference form for numerical realizing condition (7)

$$\frac{\Delta Y_t}{\Delta t}=\varepsilon Y_t-\beta Y_t^2, \qquad (8)$$

where: ΔY_t - changing mineral provision at a accounting period (t);
Δt - accounting period duration;
Y_t - mineral provision value at the accounting period t.

Solving optimization problem (7) for the model (8) made it possible for getting follow relations:

$$\beta=\frac{\sum_{t=1}^{T}Y_t^3\cdot\sum_{t=1}^{T}Y_t\cdot\Delta Y_t-\sum_{t=1}^{T}Y_t^3\cdot\sum_{t=1}^{T}Y_t^2\cdot\Delta Y_t}{\left(\sum_{t=1}^{T}Y_t^3\right)^2+\sum_{t=1}^{T}Y_t^4\cdot\sum_{t=1}^{T}Y_t^2}; \qquad (9)$$

$$Y_\infty=\frac{\frac{1}{\beta}\sum_{t=1}^{T}Y_t\cdot\Delta Y_t-\sum_{t=1}^{T}Y_t^3}{\beta\sum_{t=1}^{T}Y_t^3}. \qquad (10)$$

Formulas (9) – (10) make it possible for evaluating parameters values of the mathematical model (5). Created mathematical models make it possible for prognosis of mineral provision for environmental rational transporting and different logistical operations. The relation (5) gives the part of mineral provision and it is part of transporting minerals and allows getting prognostic information, which necessary for evaluating environmental-economical efficiency of considering logistic function.

$$F=\sum_{k=1}^{N}\left\{Y_k-\frac{Y_\infty}{\left[1+\left(\frac{Y_\infty}{Y_H}-1\right)\exp(-\varepsilon t_k)\right]}\right\}^2\lambda_k\ , \qquad (6)$$

gde je $\lambda_k=\sigma_k^{-2}$;

σ_k - srednje kvadratno odstupanje.

Parametri matematičkih modela moraju odgovarati uslovu optimalizacije, koji je u skladu sa minimalnim kriterijumom najmanjih kvadrata:

$$F\Rightarrow\min_{\{Y_\infty;\beta\}}. \qquad (7)$$

Sada napišimo diferencijalnu jednačinu (4) u obliku razlike za numerički uslov (7)

$$\frac{\Delta Y_t}{\Delta t}=\varepsilon Y_t-\beta Y_t^2, \qquad (8)$$

gde je: ΔY_t - promenljivo snabdevanje rudama u obračunskom periodu (t);
Δt - trajanje obračunskog perioda;
Y_t - vrednost snabdevanja rudama u toku obračunskog perioda t.

Rešavanje problema optimalizacije (7) za model (8) omogućilo je dobijanje sledećih izraza:

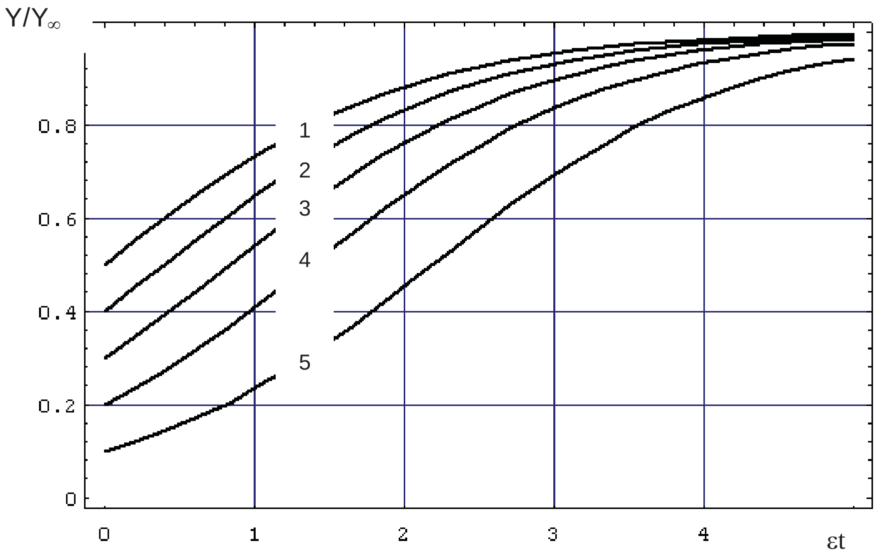
$$\beta=\frac{\sum_{t=1}^{T}Y_t^3\cdot\sum_{t=1}^{T}Y_t\cdot\Delta Y_t-\sum_{t=1}^{T}Y_t^3\cdot\sum_{t=1}^{T}Y_t^2\cdot\Delta Y_t}{\left(\sum_{t=1}^{T}Y_t^3\right)^2+\sum_{t=1}^{T}Y_t^4\cdot\sum_{t=1}^{T}Y_t^2}; \qquad (9)$$

$$Y_\infty=\frac{\frac{1}{\beta}\sum_{t=1}^{T}Y_t\cdot\Delta Y_t-\sum_{t=1}^{T}Y_t^3}{\beta\sum_{t=1}^{T}Y_t^3}. \qquad (10)$$

Formule (9) – (10) omogućavaju procenjivanje vrednosti parametara matematičkog modela (5). Stvoreni matematički modeli omogućavaju prognozu snabdevanja rudama kod ekološkog racionalnog transporta i različitih logističkih operacija. Izraz (5) daje deo snabdevanja rudama i to je deo transporta ruda koji omogućava dobijanje prognostičkih informacija, koje su neophodne za procenu ekološko-ekonomske efikasnosti u razmatranju logističke funkcije.

Results of calculating experiment by evaluating dynamic of mineral demand are shown in the Pic. 2.

Rezultati izračunavanja putem procene dinamike potražnje za rudama prikazani su na slici 2.



Picture 2 Graphic of the dependence for mineral provision function to time by Y_∞/Y_H equal to follow: 1 – 0,5; 2 - 0,4; 3 – 0,3;4 – 0,2; 5 – 0,1.

slika 2 Grafički prikaz zavisnosti funkcije snabdevanja rudama od vremena po Y_∞/Y_H jednako sledećem: 1 – 0,5; 2 - 0,4; 3 – 0,3;4 – 0,2; 5 – 0,1.

3 SUBSTANTIATING PERIODICITY OF DELIVERING MINERALS

A problem is substantiating periodicity of delivering minerals to loading points. Environmental rational transporting is characterized by economical efficiency of this process. The periodicity of delivering minerals to loading points is one major factor of the technological transport parameters. This factor influences upon environmental-logistic costs.

Consequently, environmental - logistic appropriateness stipulates necessity of evaluating optimal period, which corresponding follow condition: $\Sigma\text{Cost} \to \min$, where ΣCost are total costs of realizing environmental arrangements, standard units (s.u.).

There are two opposite tendencies during mineral transport. The first tendency is increasing cost of one transport operation by increasing transport cycles quantity at the expense of increasing costs of diesel oil and polluting atmosphere. The second tendency is decreasing exploitation casts per transport operation at expense of increasing profit during mineral selling.

3 POTVRDA UČESTALOSTI DOPREME RUDA DO MESTA UTOVARA

Problem je potvrđivanje učestalosti dopreme ruda do mesta utovara. Ekonomska efikasnost ovog procesa karakteriše ekološki racionalni transport. Učestalost dopreme ruda do mesta utovara je jedan od glavnih faktora tehnoloških parametara transporta. Ovaj faktor utiče na ekološko-logističke troškove.

Prema tome, ekološko-logistička prikladnost predviđa potrebu za procenjivanjem optimalnog perioda, koji odgovara sledećem uslovu: $\Sigma\text{Cost} \to \min$, gde su ΣCost ukupni troškovi realizacije ekoloških aranžmana, standardnih jedinica (s.j.).

Postoje dve suprotne tendencije pri transportu ruda. Prva tendencija je povećavanje troškova jedne transportne operacije putem povećanja broja transportnih ciklusa na račun povećanja troškova dizel ulja i zagađenja atmosfere. Druga tendencija je smanjivanje troškova eksploatacije po transportnoj operaciji na račun povećanja profita pri prodaji ruda.

There is optimal value of periodicity for delivering minerals to loading points (T_{tr}^{opt}) at expense of influencing these opposite tendencies. Let's consider total cost per unit dynamic for one transport operation. then increasing profit per unit at expense of increasing mass of transporting minerals during time *dt* must correspond follow balance relation: $NdP = Idt - K_C NPdt$, where N is quantity of transport operations; I is intensity of transport flow (quantity of transport operations per unit of time); K_c is constant of increasing profit per unit; P is profit per transport operation (standard units per transport operation during accounting period).

$$\frac{dP}{dt} = \frac{I}{N} - K_C P \cdot \qquad (11)$$

Let's use follow designation $P^\infty = I/(K_C N)$, then equation (11) can be written like this:

$$\frac{dP}{dt} = K_C\left(P^\infty - P\right) \cdot \qquad (12)$$

Let's integrate equation (12) for initial condition $p(0) = p_0$, where p_0 = const is initial value of profit per unit, then we get follow result:

$$P(t) = P^\infty - \left(P^\infty - P_0\right)\exp(-K_C t) \cdot \qquad (13)$$

We get follow changing cost per unit for exploitation costs at expense of increasing transport operations during time *dt*: $Nd(Cost) = -K_Э NCost\,dt$, where $Cost$ is cost per unit for one transport operation (standard units per transport operation during accounting period); $K_Э$ is constant of velocity for realizing cost per unit. The differential equation of dynamic costs per unit follows from this balance relation:

$$\frac{d}{dt}Cost = -K_Э Cost \cdot \qquad (14)$$

Let's integrate equation (14) for initial condition $cost(0) = cost_0$, where $cost_0$ = const is initial value of cost per unit, then we get follow result:

$$Cost(t) = Cost_0 \exp(-K_Э t) \cdot \qquad (15)$$

Postoji optimalna vrednost učestalosti dopremanja ruda do mesta utovara (T_{tr}^{opt}) na račun uticaja na ove suprotne tendencije. Posmatrajmo dinamiku ukupnog troška po jedinici za jednu transportnu operaciju. zatim, povećanje profita po jedinici na račun povećanja mase ruda koje se transportuju tokom vremena *dt* mora odgovarati sledećem izrazu ravnoteže: $NdP = Idt - K_C NPdt$, gde je N količina transportnih operacija; I je intenzitet toka transporta (količina transportnih operacija po jedinici vremena); K_c je konstanta povećanja profita po jedinici; P je profit po transportnoj operaciji (standardne jedinice po transportnoj operaciji tokom obračunskog perioda).

$$\frac{dP}{dt} = \frac{I}{N} - K_C P \cdot \qquad (11)$$

Koristićemo sledeću oznaku $P^\infty = I/(K_C N)$, a zatim jednačinu (11) možemo ovako napisati:

$$\frac{dP}{dt} = K_C\left(P^\infty - P\right) \cdot \qquad (12)$$

Sada upotpunimo jednačinu (12) za početni uslov $p(0) = p_0$, gde je p_0 = const početna vrednost profita po jedinici, i dobijamo sledeći rezultat:

$$P(t) = P^\infty - \left(P^\infty - P_0\right)\exp(-K_C t) \cdot \qquad (13)$$

Dobijamo sledeći promenljivi trošak po jedinici za troškove eksploatacije na račun povećanja transportnih operacija tokom vremena dt: $Nd(Cost) = -K_Э NCost\,dt$, gde je $Cost$ trošak po jedinici za jednu transportnu operaciju (standardne jedinice po transportnoj operaciji tokom obračunskog perioda); $K_Э$ je konstanta brzine za realizovanje troška po jedinici. diferencijalna jednačina dinamičkih troškova po jedinici sledi iz ovog balansnog izraza:

$$\frac{d}{dt}Cost = -K_Э Cost \cdot \qquad (14)$$

Sada upotpunimo jednačinu (14) za početni uslov $cost(0) = cost_0$, gde je $cost_0$ = const početna vrednost troška po jedinici, i dobijamo sledeći rezultat:

$$Cost(t) = Cost_0 \exp(-K_Э t) \cdot \qquad (15)$$

Total costs can be written such as follow efficiency function $\sum cost = p(t) + + cost(t)$ then optimal condition is of the form:

$$P^{\infty} - \left(P^{\infty} - P_0\right)\exp(-K_C t) + Cost_0 \exp(-K_Э t) \rightarrow \min \quad (16)$$

let's make derivation of function (16) for getting $t = T_{эм}^{opt}$, which corresponding condition $\Sigma Cost = \min$, then we get follow result:

$$\frac{d}{dt}\Sigma Cost = K_C\left(P^{\infty} - P_0\right)\exp(-K_C t) - K_Э Cost_0 \exp(-K_Э t) \quad (17)$$

the condition of $\Sigma Cost = \min$ realizes in the point $t = T_{tr}^{opt}$, where $d\Sigma Cost / dt = 0$, then we can get follow an algebraic equation for calculating numerical value T_{tr}^{opt}. Solving the equation gives follow result:

$$T_{tr}^{opt} = \frac{1}{K_Э - K_C}\ln\left|\frac{K_Э Cost_0}{K_C\left(P^{\infty} - P_0\right)}\right|. \quad (18)$$

calculating experiment results for evaluating environmental-logistic function of forming total costs by transporting minerals to loading points are shown in the Picture 3.

Ukupni troškovi se mogu izraziti kao sledeća funkcija efikasnosti $\sum cost = p(t) + + cost(t)$ tada je optimalni uslov oblika:

$$P^{\infty} - \left(P^{\infty} - P_0\right)\exp(-K_C t) + Cost_0 \exp(-K_Э t) \rightarrow \min \quad (16)$$

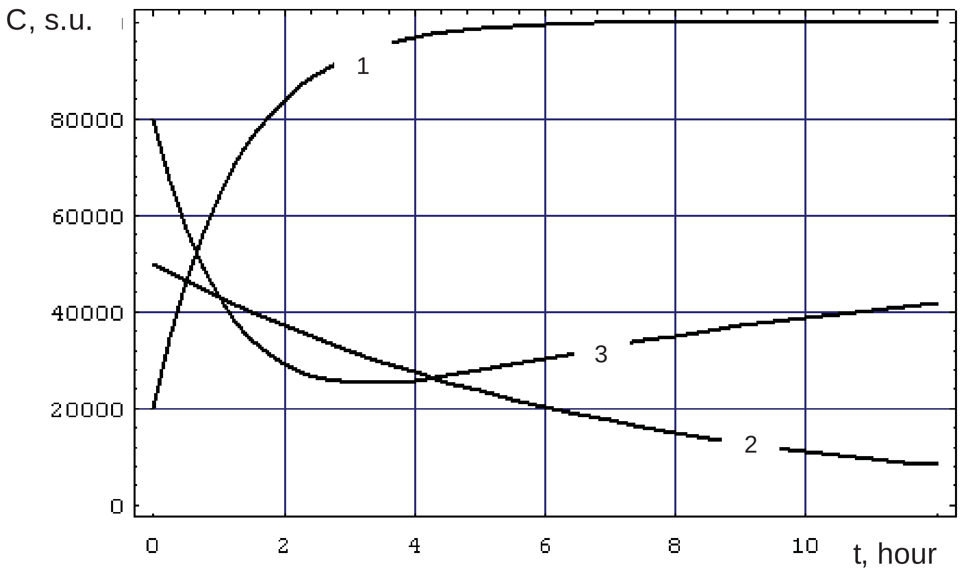
sada izvedimo funkciju (16) da bismo dobili $t = T_{эм}^{opt}$, što odgovara uslovu $\Sigma Cost = \min$, i dobijamo sledeći rezultat:

$$\frac{d}{dt}\Sigma Cost = K_C\left(P^{\infty} - P_0\right)\exp(-K_C t) - K_Э Cost_0 \exp(-K_Э t) \quad (17)$$

uslov $\Sigma Cost = \min$ ostvaruje se u tački $t = T_{tr}^{opt}$, gde je $d\Sigma Cost / dt = 0$, a zatim možemo dobiti sledeću algebarsku jednačinu za izračunavanje brojčane vrednosti T_{tr}^{opt}. Rešenje jednačine daje sledeći rezultat:

$$T_{tr}^{opt} = \frac{1}{K_Э - K_C}\ln\left|\frac{K_Э Cost_0}{K_C\left(P^{\infty} - P_0\right)}\right|. \quad (18)$$

izračunavanje rezultata ogleda za procenu ekološko-logističke funkcije nastajanja ukupnih troškova po transportu ruda to mesta utovara prikazano je na slici 3.



Picture 3 Environmental-logistic function of forming total costs by transporting minerals to loading points $P^{\infty}\cdot 10^{-4}$=10 s.u., $P_0\cdot 10^{-4}$=2 s.u., $Cost_0\cdot 10^{-4}$ = 5 s.u. 1 – Cost(t); 2 – P(t); 3 – ΣCost= f(t).
slika 3 Ekološko-logistička funkcija nastajanja ukupnih troškova po transportu ruda do mesta utovara $P^{\infty}\cdot 10^{-4}$=10 s.u., $P_0\cdot 10^{-4}$=2 s.u., $Cost_0\cdot 10^{-4}$ = 5 s.u. 1 – Cost(t); 2 – P(t); 3 – ΣCost= f(t).

5 CONCLUSION

Let's consider a real example. Let we have to evaluating periodicity of delivering minerals to loading points for follow initial data: $P^{\infty} = 10^5$ s.u.; $P_0 = 2 \cdot 10^4$ s.u.; $Cost_0 = 1{,}5 \cdot 10^4$ s.u.; $K_Э = 0{,}06$ 1/huor; $K_C = 0{,}8$ 1/hour. Calculation by formula (18) gives follow result: $T_{tr}^{opt} = 5{,}76 \cong 6$ hours.

Thus, this formula gives adequate results for initial data, which obtaining at real open pits. Simulation modeling with using formula (18) realized for determines initial data was showing that periodicity of delivering minerals to loading points is equal about 2 hours for different situations.

5 ZAKLJUČAK

Posmatrajmo jedan realan primer. recimo da treba da procenimo učestalost dopreme ruda do mesta utovara za sledeće početne podatke: $P^{\infty} = 10^5$ s.u.; $P_0 = 2 \cdot 10^4$ s.j.; $Cost_0 = 1{,}5 \cdot 10^4$ s.j.; $K_Э = 0{,}06$ 1/h; $K_C = 0{,}8$ 1/h. izračunavanje putem formule (18) daje sledeći rezultat: $T_{tr}^{opt} = 5{,}76 \cong 6$ h.

Prema tome, ova formula daje adekvatne rezultate za početne podatke, koji se dobijaju u realnim površinskim kopovima. Simulaciono modeliranje uz korišćenje formule (18) izvršeno radi određivanja početnih podataka pokazalo je da učestalost dopreme ruda do mesta utovara iznosi oko 2 sata kod različitih situacija.

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Reviewal / Recenzija: prof. dr Miloš Grujić