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CHOICE OF OPTIMAL SYSTEM FOR TRANSPORTATION OF RAW MATERIAL IN A COFFEE PROCESSING PLANT

IZBOR OPTIMALNOG SISTEMA TRANSPORTA SIROVINE U FABRICI ZA PRERADU KAFE

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Abstract: *This paper gives the comparative analysis of various solutions to the raw material transportation from the receiving silo to the system for ground coffee packing. On a real example of coffee processing plant it is obtained optimal case for raw material transportation. This paper also the analysis of efficiency of optional solutions to the raw material transportation.*

Key words: *transportation, logistics, optimization, layout*

Apstrakt: *U radu je izvršena uporedna analiza varijantnih rešenja transporta sirovine od prijemnog silosa do sistema za pakovanje mlevene kafe. Na konkretnom primeru postrojenja za preradu kafe u jednoj fabrici izvršen je izbor optimalne varijante za transport sirovine. Takođe, izvršena je i analiza efikasnosti varijantnih rešenja transporta sirovine.*

Ključne reči: *transport, logistika, optimizacija, layout*

1 INTRODUCTION

It is obvious that in many factories transportation is considered to be marginal work which is done by improvisation or in few cases as an isolated problem succeeding the choice of equipment and its assembling. Transportation system is an essential part of production and therefore it can save both time and expenses, from coming the raw material into production process to the finished products. Constant development of transportation means has made production planning easier and has decreased total costs per product unit. Development of transportation means has also influenced its variety regarding the type, capacity, energy expenditure, space necessary for installment, size of transportation paths. The project of transportation system should include the whole system of material flow, which involves not only solving

1 UVOD

Evidentno je da se u mnogim preduzećima zahtevi transporta posmatraju kao sporedni poslovi koji se rešavaju improvizacijom ili u manjem broju slučajeva kao izolovani problem nakon izbora opreme i njene montaže. Transportni sistem je integralni deo proizvodnje i znatno utiče na uštedu u troškovima u vremenu i radu, od ulaska sirovine u proces proizvodnje do izlaska gotovog proizvoda. Stalni razvoj transportnih sredstava poslednjih godina doprinosi lakšem planiranju proizvodnje i smanjenju ukupnih troškova po jedinici proizvoda. Razvoj transportnih sredstava uticao je i na pojavu njihove raznovrsne lepeze po tipu, učinku, potrošnji energije, potrebnom prostoru za ugradnju, veličini transportnih puteva. Projektovanje sistema transporta traba da obuhvati ceo sistem kretanja materijala, što znači the isolated transportation systems but planning many mutually dependant transportation requirements.

i planiranje niza međusobno zavisnih transportnih zahteva, a ne samo rešavanje izolovanih transportnih sistema.

2 ANALYSIS OF TRANSPORTATION SYSTEM

The analysis of transportation system of a coffee processing plant within the factory relates to the choice of optimal variant of transportation. Since complete equipment for coffee processing has been previously chosen, the choice of transportation means is limited a lot. Transportation from receiving ramp to the warehouse is done by means of pallet truck (Q_1=2500 kg). From the warehouse or interwarehouse the coffee is transported to the receiving container of the silo for green coffee, and then to the roasting plant (Q_2=550 kg). Roasted coffee is then transported to the mixer and after that to the grinder. After grinding the coffee is transported to the packing machines. Maximal quantity of coffee in the receiving container of packing machine is Q_p=600 kg. Diagram of transportation process is shown in figure 1.

2 ANALIZA SISTEMA TRANSPORTA

Analiza sistema transporta postrojenja u jednoj fabrici za preradu kafe odnosi se na izbor optimalne varijante transporta. Pošto je prethodno usvojena kompletna oprema postrojenja za preradu kafe izbor transportnih sredstava je u mnogome ograničen. Transport od prijemne rampe do skladišta sirovine vrši se pomoću viljuškara (Q_1=2500 kg). Iz skladišta sirovine ili međuskladišta kafa se transportuje do prijemnog bunkera sirove kafe, a odatle do postrojenja za prženje (Q_2=550 kg). Pržena kafa se dalje transportuje do miksera a zatim do mlina za mlevenje. Nakon mlevenja kafa se transportuje do mašina za pakovanje. Maksimalna količina kafe u prijemniku mašine za pakovanje iznosi Q_p=600 kg. Blok dijagram transportnih procesa prikazan je na slici 1.

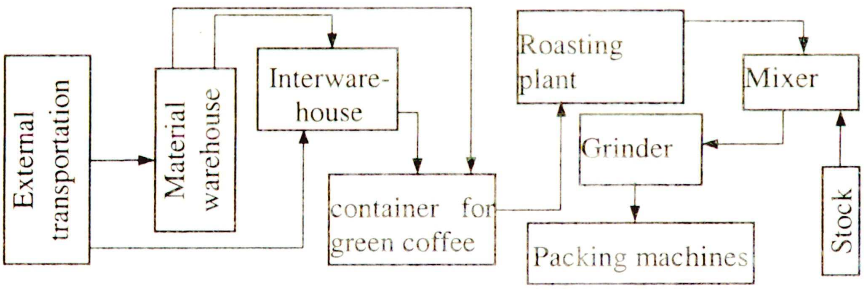

Figure 1 Diagram of transportation process
slika 1 Blok dijagram transportnih procesa

2.1 Pallet trucks transportation

According to defined parameters of transportation units (Q_1=2500 kg and Q_2=550 kg) and according to the fact that work is done in covered space the analysis has been done for electric pallet truck E12 and E30 made by "Linde". Basic technical parameters are given in table 1. Figure 2 shows transportation paths in the production plant:

L_1-warehouse-receiving container for greencoffee
L'_1-interwarehouse-receiving container for green coffee
L_2- receiving silo - roasting machine
L_3- roasting machine- mixer
L_4- mixer - grinder
L_5- grinder - packing machine

2.1. Transport viljuškarom

Saglasno definisanoj veličini transportnih jedinica (Q_1=2500 kg i Q_2=550 kg) i činjenici da se rad odvija u zatvorenom prostoru sprovedena je analiza za elektro viljuškare E12 i E30 proizvođača "Linde". Osnovni tehnički parametri dati su u tabeli 1. Na slici 2 prikazani su transportni putevi u proizvodnom pogonu:

L_1- skladište-prijemnik sirove kafe
L'_1- međuskladište-prijemnika sirove kafe
L_2- prijemni bunker-mašina za prženje
L_3- mašina za prženje-mikser
L_4- mikser-mlin
L_5- mlin- mašina za pakovanje kafe

For defined average lengths of transportation paths: $L_1=24\ m$; $L'_1=9\ m$; $L_2=15\ m$; $L_3=11\ m$; $L_4=9\ m$; $L_5=4.5\ m$; $H=2.5\ m$; $H_i=1.5\ m$; we get the average values of duration of pallet truck cycle: $T_{C.E12}=92\ s$; $T_{C.E12}=87\ s$;

Transportation system, shown in figure 2, is a closed system, where the number of units in the system is $r=6$. The average number of cycles in this system is: $\lambda = 38 \left(\frac{zah}{h}\right)$.

Za utvrđene prosečne vrednosti dužina transportnih puteva: $L_1=24\ m$; $L'_1=9\ m$; $L_2=15\ m$; $L_3=11\ m$; $L_4=9\ m$; $L_5=4.5\ m$; $H=2.5\ m$; $H_i=1.5\ m$; dobijaju se prosečne vrednosti trajanja ciklusa viljuškara: $T_{C.E12} = 92 s$; $T_{C.E30} = 87 s$;

Transportni sistem prikazan na slici 2 predstavlja zatvoreni sistem opsluživanja gde je broj jedinica u sistemu $r=6$. Utvrđeni prosečan broj zahteva u ovom sistemu iznosi: $\lambda = 38 \left(\frac{zah}{h}\right)$.

Table 1 Basic technical parameters of the pallet truck
Tabela 1 Osnovni tehnički parametri viljuškara

Technical parameters	Type of pallet truck	
	E12	*E30*
Carrying capacity (kg)	1200	3000
Lifting speed with/without load (m/s)	0.37/0.55	0.27/0.48
Lowering speed with/without load (m/s)	0.36/0.47	0.5
Driving speed with/without load (m/s)	3.1/3.5	4.2/4.4
Power for driving/lifting (kW)	6/5	12.8/13.5
Width of transportation path (mm)	1600	1800

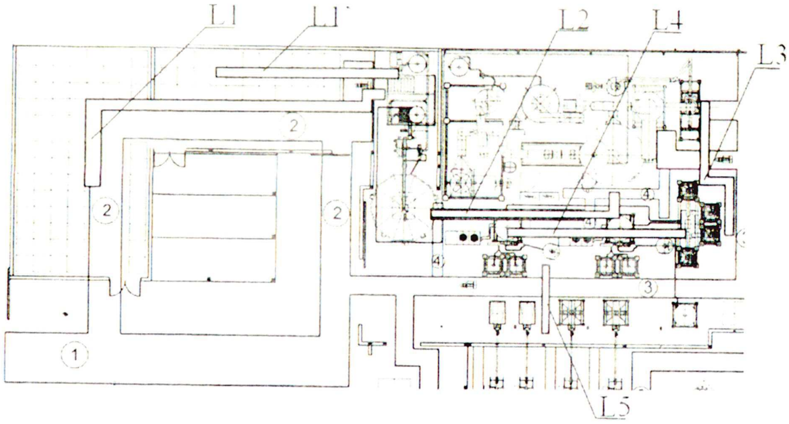

Figure 2 Transportation paths in the production plant
slika 2 Prikaz transportnih puteva u proizvodnom pogonu

Average number of units which can be supplied by pallet trucks in time unit is:

$$\mu_{E12} = \frac{1}{92} \cdot 3600 = 39.1 \quad \mu_{E30} = \frac{1}{87} \cdot 3600 = 41.4$$

Coefficient of system loading, i.e. flow intensity is:

$$\rho_{E12} = \frac{\lambda}{\mu_{E12}} = \frac{38}{39.1} = 0.972 \quad \rho_{E30} = \frac{\lambda}{\mu_{E30}} = \frac{38}{41.4} = 0.918$$

State probability of the system is [2]:

Prosečan broj jedinica koje viljuškari mogu opslužiti u jedinici vremena iznosi:

$$\mu_{E12} = \frac{1}{92} \cdot 3600 = 39.1 \quad \mu_{E30} = \frac{1}{87} \cdot 3600 = 41.4$$

Koeficijent opterećenja sistema, odnosno intenzitet protoka iznosi:

$$\rho_{E12} = \frac{\lambda}{\mu_{E12}} = \frac{38}{39.1} = 0.972 \quad \rho_{E30} = \frac{\lambda}{\mu_{E30}} = \frac{38}{41.4} = 0.918$$

Verovatnoće stanja sistema su [2]:

$$P_r = r! \cdot P_0 \cdot \left(\frac{\lambda}{\mu}\right)^r \quad (1)$$

$$P_0 = \frac{1}{1 + r \cdot \frac{\lambda}{\mu} + r \cdot (r-1) \cdot \left(\frac{\lambda}{\mu}\right)^2 + \ldots + r! \cdot \left(\frac{\lambda}{\mu}\right)^r}$$

Average number of units to be supplied is:

$$N_{zw} = \sum_{n=1}^{r} (n-1) \cdot P_n \quad (2)$$

that is: $N_{zw,E12} = 3.97;\ N_{zw,E30} = 3.91;$.

Average break-downs of units to be supplied and time needed for supply are:

$$N_{wE12} = \frac{\sum_{n=1}^{r} (n-1) \cdot P_n}{r} = 0.66;\ N_{wE30} = \frac{\sum_{n=1}^{r} (n-1) \cdot P_n}{r} = 0.65 \quad (3)$$

$$t_{wE12} = \frac{\sum_{n=1}^{r} (n-1) \cdot P_n}{r \cdot \lambda} = 1.04\,min;\ t_{wE30} = \frac{\sum_{n=1}^{r} (n-1) \cdot P_n}{r \cdot \lambda} = 1.03\,min$$

By analysis of results obtained we can conclude that a pallet truck is very busy and it cannot be used for other transportation activities so it is better to use two pallet trucks type E30. State probabilities of the system are:

$$P_0 = \frac{1}{1 + r \cdot \frac{\lambda}{\mu} + \frac{r \cdot (r-1)}{2} \cdot \left(\frac{\lambda}{\mu}\right)^2 + \ldots + \frac{r!}{c!} \cdot P_0 \cdot \left(\frac{\lambda}{\mu}\right)^2 \cdot \left(\frac{\lambda}{c \cdot \mu}\right)^4} = 0.00854$$

$$P_6 = \frac{r!}{c!} \cdot P_0 \cdot \left(\frac{\lambda}{\mu}\right)^2 \cdot \left(\frac{\lambda}{c \cdot \mu}\right)^4 = 0.345$$

Average number of units to be supplied and time needed for supply are:

$$N_{zw} = \sum_{n=c}^{r} (n-c) \cdot P_n = 2.88 \quad (4)$$

$$N_w = \frac{\sum_{n=c}^{r} (n-c) \cdot P_n}{r} = 0.48;\ t_w = \frac{\sum_{n=c}^{r} (n-c) \cdot P_n}{r \cdot \lambda} = 0.76\,min \quad (5)$$

2.2. Pneumatic transportation

The force to be realized in pneumatic line is:

$$T = \frac{\psi \cdot \rho_v \cdot A_{max}}{g} \cdot (v_v - v_M)^2 = 0.03\ daN \quad (6)$$

where: $\psi = 0.23$ - coefficient of material properties,

$$P_r = r! \cdot P_0 \cdot \left(\frac{\lambda}{\mu}\right)^r \quad (1)$$

$$P_0 = \frac{1}{1 + r \cdot \frac{\lambda}{\mu} + r \cdot (r-1) \cdot \left(\frac{\lambda}{\mu}\right)^2 + \ldots + r! \cdot \left(\frac{\lambda}{\mu}\right)^r}$$

Prosečan broj zahteva koji čeka opsluživanje je:

$$N_{zw} = \sum_{n=1}^{r} (n-1) \cdot P_n \quad (2)$$

odnosno: $N_{zw,E12} = 3.97;\ N_{zw,E30} = 3.91;$.

Prosečan zastoj jedinica za opsluživanje i vreme čekanja jedinice na opsluživanje iznosi:

$$N_{wE12} = \frac{\sum_{n=1}^{r} (n-1) \cdot P_n}{r} = 0.66;\ N_{wE30} = \frac{\sum_{n=1}^{r} (n-1) \cdot P_n}{r} = 0.65 \quad (3)$$

$$t_{wE12} = \frac{\sum_{n=1}^{r} (n-1) \cdot P_n}{r \cdot \lambda} = 1.04\,min;\ t_{wE30} = \frac{\sum_{n=1}^{r} (n-1) \cdot P_n}{r \cdot \lambda} = 1.03\,min$$

Analizom dobijenih rezultata može se zaključiti da je visoka zauzetost jednog viljuškara i ne može se koristiti za dopunske aktivnosti transporta pa je bolje rešenje usvojiti dva viljuškara E30. Verovatnoće stanja sistema su:

$$P_0 = \frac{1}{1 + r \cdot \frac{\lambda}{\mu} + \frac{r \cdot (r-1)}{2} \cdot \left(\frac{\lambda}{\mu}\right)^2 + \ldots + \frac{r!}{c!} \cdot P_0 \cdot \left(\frac{\lambda}{\mu}\right)^2 \cdot \left(\frac{\lambda}{c \cdot \mu}\right)^4} = 0.00854$$

$$P_6 = \frac{r!}{c!} \cdot P_0 \cdot \left(\frac{\lambda}{\mu}\right)^2 \cdot \left(\frac{\lambda}{c \cdot \mu}\right)^4 = 0.345$$

Prosečan broj zahteva koji čeka na opsluživanje i vreme čekanja na opsluživanje iznose:

$$N_{zw} = \sum_{n=c}^{r} (n-c) \cdot P_n = 2.88 \quad (4)$$

$$N_w = \frac{\sum_{n=c}^{r} (n-c) \cdot P_n}{r} = 0.48;\ t_w = \frac{\sum_{n=c}^{r} (n-c) \cdot P_n}{r \cdot \lambda} = 0.76\,min \quad (5)$$

2.2. Pneumatski transport

Sila koju treba ostvariti u pneumatskom vodu je:

$$T = \frac{\psi \cdot \rho_v \cdot A_{max}}{g} \cdot (v_v - v_M)^2 = 0.03\ daN \quad (6)$$

gde je: $\psi = 0.23$ - koeficijent svojstva materijala,

$A_{max} = 0.011\ m^2$ - projection of the area of the biggest section perpendicular to flow speed,

$\rho_M = 440\ kg/m^3$ - density of coffee beam,

$\rho_v = 1.2\ kg/m^3$ - air density,

$v_v = 15\ m/s$ - chosen air speed,

v_m - speed of mixture flow.

For pressure fall in the air line $\Delta p_v = 0.025 MPa$, the value of pressure in delivery line is $p_p = 0.36 MPa$, where:

$L_r = 31\ m$ - reduced pipeline length

$L_v = 8\ m$ - reduced vertical pipeline length

Air quantity needed for transportation of coffee beam is:

$$V_k = 0.785 \cdot d_c^2 \cdot v_v = 0.17\ m^3/s \quad (7)$$

where: $d_c = 0.13\ m$ - pipeline diameter.

Based on theoretical operation of air machine: $A_M = 230300 \cdot p_b \cdot \log \frac{p_M}{p_b} = 12811.6\ Nm/m^3$ we obtain the power of driving electromotor needed to realize the operation of machine of air transportation:

$$P_M = \frac{A_M \cdot V_k}{\eta} = 3.6\ kW$$ - adopted $P_M = 4\ kW$.

Capacity of realized transportation is:

$$Q_m = \frac{D^2 \cdot \pi \cdot v_M \cdot \rho_v \cdot c}{4} = 1.5\ kg/s = 90\ kg/min$$

Capacity to be realized is: $Q_p = 60\ kg/min$.

The receiving silo is unloaded for 10 minutes at least. For other transportation cycles (L'$_1$, L_2, L_3, L_4 and L_5) and for the same capacity the necessary power of driving aggregates is: $P_M = 3\ kW$.

Average quantity of material leaving the receiving silo in one cycle is: $Q_l = 550\ kg$. Average number of cycles during one working hour is 4.

$A_{max} = 0.011\ m^2$ - projekcija površine najvećeg preseka upravno na brzinu strujanja,

$\rho_M = 440\ kg/m^3$ - gustina kafe u zrnu,

$\rho_v = 1.2\ kg/m^3$ - gustina vazduha,

$v_v = 15\ m/s$ - usvojena brzina vazduha,

v_m - brzina strujanja mešavine

Za pad pritiska u vazdušnom vodu $\Delta p_v = 0.025 MPa$, vrednosti pritiska potisnog uređaja iznosi $p_p = 0.36 MPa$, pri čemu je poznato:

$L_r = 31\ m$ - redukovana dužina cevovoda

$L_v = 8\ m$ -redukovana vertikalna dužina cevovoda

Potrebna količina vazduha za transport kafe u zrnu iznosi:

$$V_k = 0.785 \cdot d_c^2 \cdot v_v = 0.17\ m^3/s \quad (7)$$

gde je: $d_c = 0.13\ m$ - prečnik cevovoda.

Na osnovu teorijskog rada mašine za vazduh: $A_M = 230300 \cdot p_b \cdot \log \frac{p_M}{p_b} = 12811.6\ Nm/m^3$ dobija se potrebna snaga pogonskog elektromotora za rad mašine za vazdušni transport:

$$P_M = \frac{A_M \cdot V_k}{\eta} = 3.6\ kW$$ - usvojeno $P_M = 4\ kW$.

Kapacitet ostvarenog transporta iznosi:

$$Q_m = \frac{D^2 \cdot \pi \cdot v_M \cdot \rho_v \cdot c}{4} = 1.5\ kg/s = 90\ kg/min$$

Potreban kapacitet koji treba ostvariti iznosi: $Q_p = 60\ kg/min$.

Najmanje vreme pražnjenja prijemnog bunkera iznosi 10 minuta. Za ostale transportne cikluse (L'$_1$, L_2, L_3, L_4 и L_5) i isti kapacitet potrebna snaga pogonskih agregata isnosi: $P_M = 3\ kW$.

Prosečna vrednost količine materijala koja izlazi z prijemnog bunkera, u jednom ciklusu, iznosi $Q_l = 550\ kg$. Prosečan broj ciklusa u jednom satu rada postrojenja je 4.

If arriving flow acts according to Poisson distribution, the flow intensity and average material quantity to be supplied is:

$$\rho = \frac{\lambda}{\mu} < 1; \quad \lambda = \frac{Q_1 \cdot n_c}{60} = \frac{550 \cdot 4}{60} = 36.7\ kg/min$$

For average system efficiency of 70% the value of material flow is:

$$\mu = \frac{36.7}{0.7} = 52.4\ kg/min$$

Real flow intensity is: $\rho_{st} = 0.41$.

Average number of units to be supplied in one-channel system (1 kg is 1 unit) is:

$$N_w = \frac{\rho^2}{2 \cdot (1-\rho)} = 0.14\ kg$$

2.3 Belt conveyer and bucket elevator transportation

Required capacity can be acquired by coupled system: bucket elevator and belt conveyer.

Adopted technical parameters of the elevator are:

$Q=4.4t/h$ – transportation capacity, $i_o=0.4\ dm^3$ - bucket volume, $n_k=260$ - number of buckets, $t_k=007m$ - bucket pitch, $n_c=120c/h$ - number of unloading.

Driving volume of buckets and driving weight of load are:

$$i_p = \frac{i_0}{t_k} = 0.005\ \left(\frac{m^3}{m}\right); \quad q_G = i_p \cdot \psi_p \cdot \rho = 1.9\ \ (kg/m);$$

where: $\psi_p = 0.85$ - coefficient of bucket loading.

Approximate value of driving weight of moving parts is:

$$q_E = k_E \cdot Q = 2.64\ \ (kg/m)$$

where $k_E = 0.6$ - coefficient of driving mass.

Needed power of elevator driving engine is:

Ukoliko se dolazni tok ponaša po Poason-ovoj raspodeli intenzitet protoka i prosečna količina materijala koju treba opslužiti iznose:

$$\rho = \frac{\lambda}{\mu} < 1; \quad \lambda = \frac{Q_1 \cdot n_c}{60} = \frac{550 \cdot 4}{60} = 36.7\ kg/min$$

Za usvojeno prosečno iskorišćenje sistema od 70% potrebna vrednost protoka materijala je:

$$\mu = \frac{36.7}{0.7} = 52.4\ kg/min$$

Stvarni intenzitet protoka iznosi: $\rho_{st} = 0.41$.

Prosečan broj jedinica u redu čekanja jednokanalnog sistema opsluživanja (1 kg je jedna jedinica) iznosi:

$$N_w = \frac{\rho^2}{2 \cdot (1-\rho)} = 0.14\ kg$$

2.3 Transport trakastim transporterom i elevatorom sa koficama

Zahtevani kapacitet može se ostvariti korišćenjem spregnutog sistema elevatora sa koficama i trakastog transportera.

Usvojeni tehnički parametri elevatora su:

$Q=4.4t/h$ – kapacitet transporta, $i_o=0.4\ dm^3$ - zapremina kofice, $n_k=260$ - broj kofica, $t_k=007m$ - korak kofice, $n_c=120c/h$ - broj pražnjenja kofica.

Pogonska zapremina kofica i pogonska masa tereta iznose:

$$i_p = \frac{i_0}{t_k} = 0.005\ \left(\frac{m^3}{m}\right); \quad q_G = i_p \cdot \psi_p \cdot \rho = 1.9\ \ (kg/m);$$

gde je: $\psi_p = 0.85$ - koeficijent punjenja kofica

Približna vrednost pogonske mase pokretnih delova elevatora iznosi:

$$q_E = k_E \cdot Q = 2.64\ \ (kg/m)$$

pri čemu je $k_E = 0.6$ - koeficijent pogonske mase

Potrebna snaga pogonskog motora elevatora iznosi:

$$P=\frac{1}{3600}\cdot Q\cdot g\cdot H\cdot\left(1+\frac{k_p}{H}\right)=\frac{1}{3600}\cdot 4.4\cdot g\cdot 4.5\cdot\left(1+\frac{2}{4.5}\right)=0.1\ (kW)$$

so adopted power is: $P_M = 0.75\ kW$.

By unloading the elevator, the material is put to the straight belt conveyer (figure 3).

The resistance in return run is:

$$W_{1-2}=g\cdot(q_r+q_T)\cdot L\cdot\omega=41\ N$$

where:

$$q_r=(10\cdot B+K)/l=10\ kg/m$$

$q_T = 0.44\ kg/m$ - driving mass of the belt

$\omega = 0.02$ - coefficient of friction between belt and pulley

The resistance over the tension drum is:

$$W_{2-3}=(k_p-1)\cdot S_2$$

where: $k_p = 1.07$ - coefficient of resistance.

$$W_{2-3} = 2.87 + 0.07\cdot S_1$$

Resistance in straight loaded part is:

$$W_{3-4}=g\cdot(q_G+q_T+q_g)\cdot L\cdot\omega=45.8\ N$$

Maximal value of the force is:

$$S_{max}=k_p\cdot S_4=1.15\cdot S_1+96$$

so:

$$\frac{S_{max}}{S_1}=\frac{1.15\cdot S_1+96}{S_1}=\frac{S_{max}}{S_1}=2.56$$

Values of forces in the points 1, 2, 3, 4 are:

$S_1=68\ N;\ S_2=109\ N;\ S_3=116.6\ N;\ S_4=162.5\ N;$
$S_{max}=174\ N;\ F_0=106\ N$

Belt speed necessary to realized the required capacity is $v=0.8\ m/s$; so the power of driving aggregate is:

$$P=\frac{F_0\cdot v}{\eta}=\frac{106\cdot 0.8}{0.55}=154\ W$$ -adopted:- $P_M=0.75\ kW$

$$P=\frac{1}{3600}\cdot Q\cdot g\cdot H\cdot\left(1+\frac{k_p}{H}\right)=\frac{1}{3600}\cdot 4.4\cdot g\cdot 4.5\cdot\left(1+\frac{2}{4.5}\right)=0.1\ (kW)$$

pa je usvojena snaga: $P_M = 0.75\ kW$.

Pražnjenjem elevatora materijal se nasipa na pravolinijski trakasti transporter (slika 3).

Otpor u povratnoj grani iznosi:

$$W_{1-2}=g\cdot(q_r+q_T)\cdot L\cdot\omega=41\ N$$

gde je:

$$q_r=(10\cdot B+K)/l=10\ kg/m$$

$q_T = 0.44\ kg/m$ - pogonske mase trake

$\omega = 0.02$ -koeficijent trenja trake i doboša

Otpor preko zateznog doboša iznosi:

$$W_{2-3}=(k_p-1)\cdot S_2$$

gde je: $k_p = 1.07$ - koeficijent otpora.

$$W_{2-3} = 2.87 + 0.07\cdot S_1$$

O
tpor u pravolinijskom opterećenom delu iznosi:

$$W_{3-4}=g\cdot(q_G+q_T+q_g)\cdot L\cdot\omega=45.8\ N$$

Maksimalna vrednost sile iznosi:

$$S_{max}=k_p\cdot S_4=1.15\cdot S_1+96$$

tako da je odnos:

$$\frac{S_{max}}{S_1}=\frac{1.15\cdot S_1+96}{S_1}=\frac{S_{max}}{S_1}=2.56$$

Vrednosti sila u odgovarajućim tačkama iznose:

$S_1=68\ N;\ S_2=109\ N;\ S_3=116.6\ N;\ S_4=162.5\ N;$
$S_{max}=174\ N;\ F_0=106\ N$

Potrebna brzina kretanja trake za projektovani kapacitet iznosi $v=0.8\ m/s$; ; tako da je snaga pogonskog agregata:

$$P=\frac{F_0\cdot v}{\eta}=\frac{106\cdot 0.8}{0.55}=154\ W$$ - usvojeno:- $P_M=0.75\ kW$

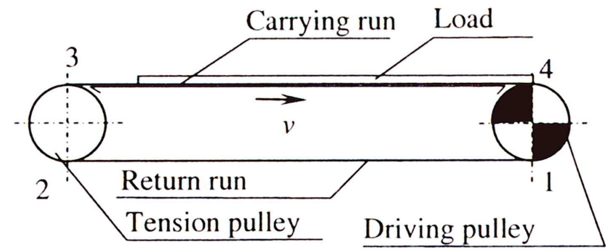

Figure 3 Diagram for calculation of conveyer
slika 3 Karakteristine tačke za proračun transportera

For other transportation cycles (L'_1, L_2, L_3, L_4 L_5) and same capacity, the power of driving aggregates required is: $P_M = 0.55\ kW$.

Average material quantity to be supplied is:

$$\lambda_t = \frac{Q_l \cdot n_c}{60} = \frac{550 \cdot 4}{60} = 36.7\ kg/min$$

If average system efficiency is 70%, the average value of material flow to be provided is:

$\mu = \frac{36.7}{0.7} = 52.4\ kg/min$ so real flow intensity is:

$\rho_{st} = 0.51$.

Average number of units to be supplied in one-channel system is (if 1kg is 1 unit):

$$N_w = \frac{\rho^2}{2 \cdot (1-\rho)} = 0.27\ kg$$

Chances for overloading during operation is:

$$P_{(n>N)} = \sum_{n=N}^{\infty} \rho^n \cdot (1-\rho) = \rho^{N+1} = 0.52^{37} = 3 \cdot 10^{11}$$

3. COMPARATIVE ANALYSIS AND CHOISE OF TRANSPORTATION SYSTEM

Comparative analysis should provide the choice of optimal variant based on a number of required criteria.

In terms of mathematics, the optimization is based on search for extreme values of criterion function s [7]:

$$Max\{f_1(x), f_2(x), ..., f_n(x) \quad n \geq 2\} \qquad (12)$$

with defined limitations:

Za ostale transportne cikluse (L'_1, L_2, L_3, L_4 L_5) i isti kapacitet potrebna snaga pogonskih agregata iznosi: $P_M = 0.55\ kW$.

Prosečna količina materijala koju je neophodno opslužiti (ide dalje u proces) iznosi:

$$\lambda_t = \frac{Q_l \cdot n_c}{60} = \frac{550 \cdot 4}{60} = 36.7\ kg/min$$

Ako je prosečno iskorišćenje sistema 70%, potrebna prosečna vrednost protoka materijala koju treba obezbediti iznosi:

$\mu = \frac{36.7}{0.7} = 52.4\ kg/min$ pa je stvarni intenzitet protoka:

$\rho_{st} = 0.51$.

Prosečan broj jedinica u redu čekanja (ukoliko se usvoji da je 1 kg jedna jedinica) za jednokanalni sistem opsluživanja iznosi:

$$N_w = \frac{\rho^2}{2 \cdot (1-\rho)} = 0.27\ kg$$

Verovatnoća da će doći do prepunjavanja u radu je:

$$P_{(n>N)} = \sum_{n=N}^{\infty} \rho^n \cdot (1-\rho) = \rho^{N+1} = 0.52^{37} = 3 \cdot 10^{11}$$

3. UPOREDNA ANALIZA I IZBOR TRANSPORTNOG SISTEMA

Zadatak uporedne analize jeste da se omogući izbor optimalne varijante na osnovu većeg broja zadatih kriterijuma.

U matematičkom obliku optimizacija se svodi na traženje ekstrema kriterijumskih funkcija [7]:

$$Max\{f_1(x), f_2(x), ..., f_n(x) \quad n \geq 2\} \qquad (12)$$

pri zadatim ograničenjima:

$$x \in A\left[A1, A2, ..., Am\right] \qquad (13)$$

where: n – criterion number,
m – alternative number,
f_j – criteria,
A_i – alternatives for consideration.

During consideration, values f_{ij} are known for each criterion f_j for each possible alternative A_i:

$$f_{ij} = f_j(A_i);\ \forall(i,j);\ i = 1,2,...,m;\ j = 1,2,...,n; \qquad (14)$$

The problem is solved by MODIPROM method [6] which is based on improving the group of methods for multicriteria ranging named PROMETHEE. The values of criterion functions and alternatives of transportation are shown in table2.

$$x \in A\left[A1, A2, ..., Am\right] \qquad (13)$$

gde su: n – broj kriterijuma,
m – broj alternativa,
f_j – kriterijumi,
A_i – alternative za razmatranje.

U razmatranju su poznate vrednosti f_{ij} svakog razmatranog kriterijuma f_j za svaku od mogućih alternativa A_i:

$$f_{ij} = f_j(A_i);\ \forall(i,j);\ i = 1,2,...,m;\ j = 1,2,...,n; \qquad (14)$$

Rešavanje razmatranog problema izvedeno je metodom MODIPROM [6] koja je zasnovana na poboljšanju grupe metoda za višekriterijumsko rangiranje poznatih pod nazivom PROMETHEE. Vrednosti kriterijumskih funkcija i alternative transporta prikazane su u tabeli 2.

Table 2. Values of criterion functions
Tebela 2. Vrednosti kriterijumskih funkcija

Criterion type	Discontinuous transportation	Continuous transportation		Optimization criterion	Priority level
	A1	A2	A3		
K1	264	0.14	0.27	min	1.3
K2	0.8	0.14	0.31	min	1.2
K3	26.3	16	15.5	min	1
K4	41400	27000	21600	max	1
K5	0.46	0.41	0.51	min	1

Criteria for analysis are:

K1 – Average number of units to be supplied
K2 – Level of free areas being busy
K3 – Energy expenditure
K4 – Realized capacity of transportation
K5 – Flow intensity

Alternatives are:

A1 – Transportation by pallet trucks type E30
A2 – Pneumatic transportation
A3 – Transportation by elevator and conveyer

The results of analysis done by the program package MODIPROM are shown in figure 4.

Based on the analysis carried out, it is chosen the pneumatic transportation between the machines except for the transportation from the grinder to the packing machines where we chose the third alternative. Diagram of regulating the transportation process is shown in figure 5.

Kriterijumi za analizu su:

K1 – Prosečan broj jedinica u redu čekanja
K2 – Stepen zauzetosti slobodnih površina
K3 – potrošnja energije
K4 – Ostvareni kapacitet transporta
K5 – Intenzitetprotoka

Alternative su:

A1 – transport viljuškarima E30
A2 – Pneumatski transport
A3 – transport elevatorom i transporterom

Rezultati analize programskim paketom MODIPROM prikazani su na slici 4.

Na osnovu izvršene analize izabran je pneumatski transport između mašina izuzev transporta od mlina do mašina za pakovanje gde je izabrana treća alternativa. Blok dijagram upravljanja procesom transporta prikazan je na slici 5.

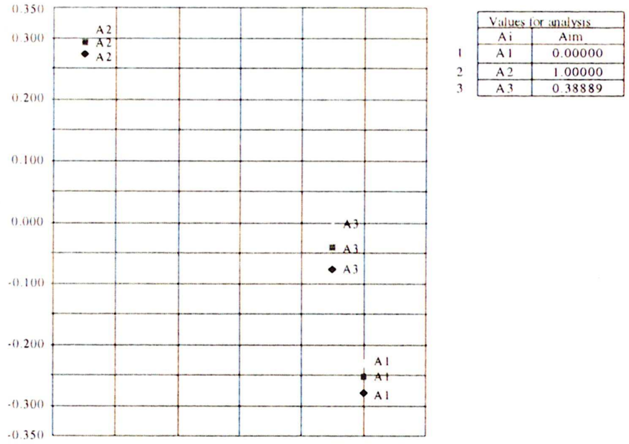

Figure 4 Values of criterion functions for defined alternatives
slika 4 Vrednosti kriterijumskih funkcija za zadate alternative

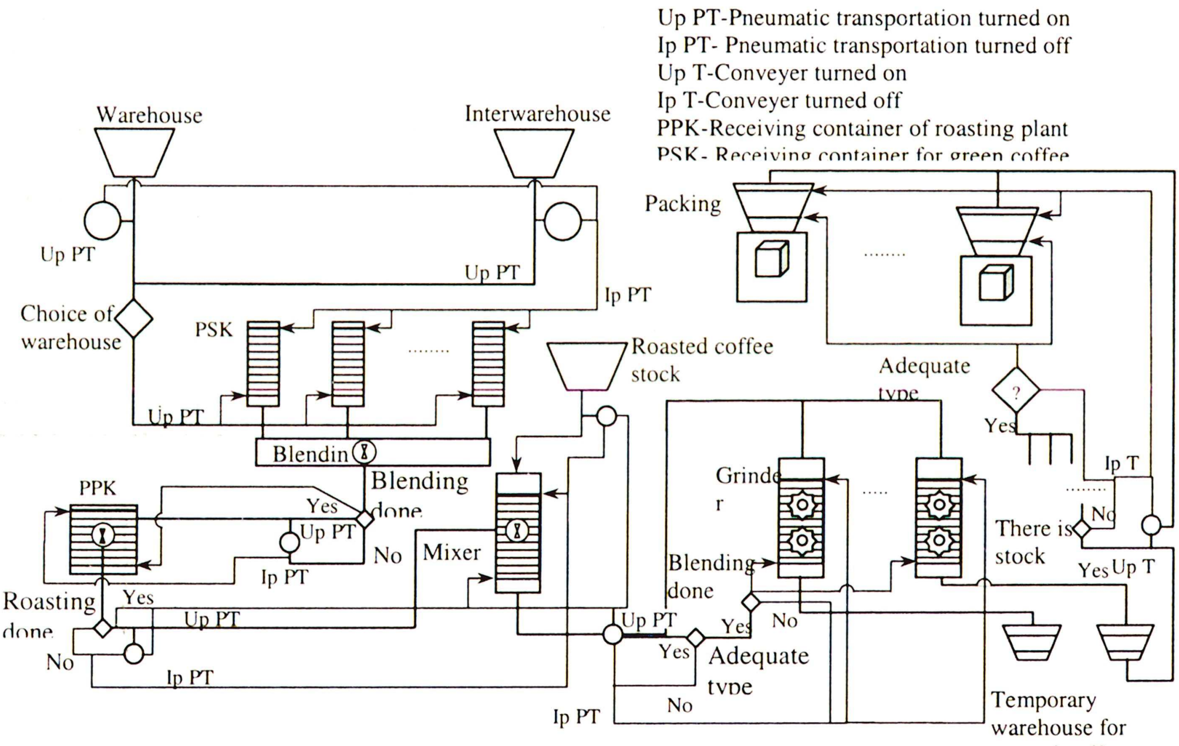

Figure 5 Diagram of regulating the transportation process
slika 5 Blok dijagram upravljanja procesom transporta

4 CONCLUSION

The given analysis provides optimal solution for internal transportation based on a number of criteria. Presented method does not depend on the number of analysis criteria nor on the number of alternatives. The optimal solution reached in this paper has many advantages over other solutions so it is necessary to do the analysis before final layout of equipment and installations.

4 ZAKLJUČAK

Sprovedenom analizom dolazi sei do optimalnog rešenja procesa unutrašnjeg transporta prema većem broju kriterijuma. Izloženi postupak ne zavisi od broja kriterijuma za analizu kao ni od broja alternativa. Dobijeno optimalno rešenje ima niz prednosti u odnosu na druga rešenja pa je neophodno analizu sprovesti pre konačnog rasporeda opreme i instalacija.

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