SELECTING OF THE APPROPRIATE MACHINE TYPES FOR CERTAIN BUILDING INDUSTRIAL TASKS

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Summary

The paper discusses a system of indices which has been developed on the basis of technical/economical analysis. Using the system of indices the efficiency of the running building machine can be evaluated, and the rational structure of the machine park can also be determined. The introduced method can provide a useful tool for the decision procedure of selection of the building machines.

These days the structure of the building machines is constantly improved and gets more and more complex, and special steal alloys and new structural elements/materials are used for producing. Consequently more safe operation and higher capacity can be achieved on the one hand, but the price of each building technological unit gets more expensive on the other one. Therefore, when the machine group needed for a given building technological process is purchased, a concise technical-economical analysis should be made to utilise more economically the machine group selected.

This task can be solved in three subsequent steps, as follows:

— setting up the system of criteria by which some operation efficiency of the machines can be determined,

— demonstration and analysis of producing factors affecting the efficient application of the machines,

— developing of predicting methods by which the future machine park — taking also into consideration its application conditions — can be determined.

Setting up the system of criteria to evaluate operation efficiency of building machines

The main criterion by which the most effective index of operation efficiency can be determined considers the total costs of producing unit of building industrial product. This role can be satisfied by the s.c. specific reduced cost z_{spec}. According to the recommendation of the State Building Committee of SU (GOSZ SZTROJ [1]), the value of z_{spec} can be determined, as follows:

$$z_{\text{spec}} = [K_b(F + H_n) + U + H_n \cdot B_1]\, 1/V_y \quad (\text{rub/unit}) \qquad (1)$$

where

K_b — the initial costs of the machine, in conjunction with producing/purchasing/shipping/installation; rub/year.

F — percentage of renewal deduction related to the initial costs.

H_n — normal efficiency factor of establishment charges ($H_n = 0.15$).

U — running costs of the user, in conjunction with performance of technological process; rub/year.

B_1 — operational establishments/installations of the user rub/year.

V_y — the yearly operational capacity of the machine; unit/year.

More detailed:

$$K_b = K_1 \cdot t_b \quad \text{(rub/piece)} \tag{2}$$

where

K_1 — outlay/production costs of the machine; rub/item.

t_b — a factor considering the shipping/installation costs of the machine.

$$F = E(1 + E)^{T_l} - 1 \tag{3}$$

where

E — normative renewal factor

T_l — the life-time of the machine, year.

$$U = S_1 + S_2 + S_3 + S_4 + S_5 + S_6 + S_7 + S_8 + S_9 + S_{10} \quad \text{(rub/year)} \tag{4}$$

where

S_1 — general reparation costs

S_2 — wages of the operators

S_3 — the yearly maintenance/running reparation costs

S_4 — total fuel costs

S_5 — costs of hydraulic oil

S_6 — lubricant costs

S_7 — relocation cost of the machine within a year

S_8 — cost of tyres

S_9 — costs of replacable accessories

S_{10} — amortization costs of linked establishments

$$S_1 = K_2 \cdot A_1 \cdot K_b/100 \quad \text{rub/year} \tag{5}$$

where

K_2 — factory overhead costs related to the reduced running costs

A_1 — percentage, put aside for general reparation.

$$S_2 = K_3 \cdot K_1 \cdot \lambda \cdot T_1 \sum_{i=1}^{B} C_i \quad \text{rub/year} \tag{6}$$

where

K_3 — overhead costs calculated from the total wages
K_4 — correction factor
λ — a factor considering premium bonus
T_1 — running hours per year
B — the number of operators per shift
C_i — the hourly basis of the operating personnel ranked to category i, rub.

$$S_3 = S_3' + S_3'' \quad \text{rub/year} \tag{7}$$

where

S_3' — wages of the maintenance personnel
S_3'' — material & part costs

$$S_3' = T_1/T_2 \cdot K_8 \cdot \lambda_p \cdot C_p \sum_{j=1}^{m} a_j G_j \quad \text{rub/year} \tag{8}$$

where

T_1 — the yearly time basis of the machine, running hours
T_2 — period between subsequent preparations
λ_p — a factor considering the premium bonus of the maintenance personnel
C_p — hourly wage basis of a maintenance worker
m — the number of maintenance/reparation work types
a_j — number of maintenance/reparation works of type j.
G_j — man-power requirement of maintenance/reparation work of type j.

$$S_3'' = K_2 \cdot S_3'/K_3 \cdot K_5 \quad \text{rub/year} \tag{9}$$

where

K_b — the transition factor from wages to maintenance/repair costs
The other notations of Eq. 9 have already been explained.

$$S_4 = K_2 \cdot \acute{A}_t \cdot W_t \cdot T_1 \quad \text{rub/year} \tag{10}$$

where

$\acute{A}_t$ — fuel costs rub/kg
W_t — fuel consumption, kg/hour

$$W_t = 1.03 \cdot 10^{-3} \cdot Ne \cdot fe \cdot K_N \cdot K_6 \cdot K_7 \quad \text{kg/h} \tag{11}$$

where

Ne — the rated power, kw
fe — specific fuel consumption under rated condition, g/kwh
K_N — a factor considering the change in fuel consumption in the function of consumed power

K_6 — a time factor of engine utilisation
K_7 — the power consumption factor of the engine.

$$S_{11} = K_2 \cdot V_h \cdot \gamma_m \cdot A_2 \cdot K_h \cdot T_1/t_h, \quad \text{rub/year} \tag{12}$$

where
V_h — the volume of the hydraulic system, dm^3
γ_m — the specific mass content of the hydraulic oil, kg/dm^3
A_2 — the unit price of the oil, when purchased on large-scale
K_h — oil consumption factor
t_h — oil change period, running hour

$$S_6 = \xi \cdot S_t \quad \text{rub/year} \tag{13}$$

where
ξ — transition factor from yearly fuel costs to lubricant costs

$$S_9 = (S_7 + S_{13} + S_{14}) \cdot T_1/T_3 \quad \text{rub/year} \tag{14}$$

where
T_3 — dwelling period of the machine at a site/object

$$T_3 = V/B_2 \quad \text{running hour} \tag{15}$$

V — the volume of work done in-situ
B_2 — the hourly field capacity of the machine
S_7 — the cost of a single relocation of the machine, rub.
S_{12} — installation costs, rub.
S_{13} — dismount costs, rub.

$$S_7 = S_7' + S_7'' \quad \text{rub} \tag{16}$$

where
S_7' — transportation cost of the machine rub.
S_7'' — transportation cost of the self-moving machine, rub.

$$S_7' = S_{14} + S_{15} \quad \text{rub} \tag{17}$$

where
S_{14} — the wage costs of the transportational personnel, if transported on trailer or by towing, rub.
S_{15} — the operational costs of the machine/transportation/installation tools, rub.

$$S_{14} = [S_b + (L - L_n)S_{16}] \cdot K_8 \quad \text{rub} \tag{18}$$

where
S_b — wage cost for a given transportation distance, rub.
L — transportation distance, km
L_n — the transportation distance specified, km

S_{16} — additional costs of each km beyond the specified transportation distance L_n.

$$S_{15} = [Sz_0 + (L - L_n)Sz_a] \cdot K_2 \quad \text{rub} \tag{19}$$

where

Sz_0 — transportation costs for specified distance

Sz_a — additional costs per km, beyond the specified distance L_n, rub/km.

$$S_7'' = S_2 \cdot L/V_1 \quad \text{rub} \tag{20}$$

where

V_1 — the average advancement velocity, km/h.

$$S_8 = K_2 \cdot \hat{A}_3 \cdot n_1 \cdot (T_1 \cdot T_4 - T_5)/(T_4 \cdot T_5) \tag{21}$$

where

$\hat{A}_3$ — unit price of the tyre, rub.

n_1 — the number of the tyres within one set

T_6 — life time of the tyres, running hour.

The other notations have already been explained.

The costs of the replaceable accessories S_{tar} can be determined for each machine type by taking into consideration the effective accessory/part consumption/utilisation during certain running periods. The amortization deductions S_{am} in connection with joint establishments can be determined in the function of the actual establishments (e.g. new buildings, workshops, stores, parking places, etc.) of the company in a given period of time.

If the Eqs (2) to (21) were treated together it would result in a rather complex relationship, thus it is worth doing some reconstruction. Therefore the indices characterizing the construction by groups and the capacity of the machines and the costs of producing should be consolidated/compacted. Further, if e.g. a given machine is considered, the production cost per time unit is constant, so it can be factored out. The Eqs (1) to (21) can then be reshaped in the following manner:

$$Z_{\text{spec}} = (L \cdot b + C)/V + a/B_2 \quad \text{rub/unit} \tag{22}$$

where

L — transportation distance to the next work site, km

V — the volume of the work to be done in-situ

a — constant, characterizing the purchasing/operation costs of the machine related to one running hour, rub/h

b — constant, characterizing the cost of unit distance transportation, rub/km

C — constant, characterizing the simultaneous costs of a given transportation.

Determination of rational fields of application of building machines

The mathematical model Eq. (22) can be used to evaluate the various mechanization schemes of building tasks operatively, to forecast the efficiency level of new variants/schemes and to establish building machine park with corresponding work conditions.

In the course of evaluating different variants/schemes, an information basis of norms is created, thus the values of constants "a", "b" and "c" are determined. The specific reduced costs are calculated for each variant.

As optimal, the variant with $z_{\mathrm{spec}} = \min !$ is to be selected. This method can be applied without computers, directly at the company, for informative purposes.

The efficacy of new appliances is predicted so that the specific reduced costs calculated by computers are compared.

By this method, different technical, economical and operational factors can simultaneously be considered and all the variants can be analysed.

To establish a rational machine-park, the method of equal efficacy can be applied (2). The essence of this method is that all variants are taken and analysed subsequently. The object function in this case is

$$z_{\mathrm{spec}} = \min !$$

with the constraints of

$$z_{\mathrm{spec}(i)} = z_{\mathrm{spec}(i+1)},\ V = \text{const.},\ L = \text{const.}, \text{ where}$$

$z_{\mathrm{spec}(i)}$; $z_{\mathrm{spec}(i+1)}$ are the specific reduced costs of the variants i and $(i + 1)$, respectively.

By repeated calculations of the variants, such set of points is created by which a line in the V—L coordinate plane, the s. c. isoefficiency-line is formed. This line can be derived from Eq. (22) in the following way:

$z_{\mathrm{spec}(i)} = z_{\mathrm{spec}(i+1)}$

$$\frac{L \cdot b_{(i+1)} + c_{(i+1)}}{V} + \frac{a_{(i+1)}}{B_{3(i+1)}} = \frac{L \cdot b_i + c_i}{V} + \frac{a_i}{B_{3(i)}} \tag{23}$$

where

$$V = \{L[b_{(i+1)} - b_i] + [c_{(i+1)} - c_i]\} \cdot \frac{B_{3i} \cdot B_{3(i+1)}}{a_i \cdot B_{3(i+1)} - a_{(i+1)} \cdot B_{3i}} \tag{24}$$

The graphical presentation of the isoefficiency lines can be seen in Fig. 1. By the means of the nomogram obtained, the rational variant of mechanization can be selected under given work volume and transportation distance.

If the intersections on the axes O—V and O—L belonging to any given values of V and L are higher than that of $z_{\mathrm{spec}(i)} = z_{\mathrm{spec}(i+1)}$ and $z_{\mathrm{spec}(i+1)} = z_{\mathrm{spec}(i+2)}$, then the $(i + 1)$th variant is to be applied, and so on.

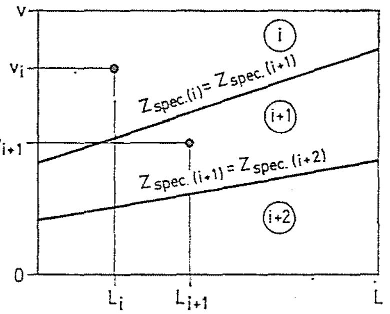

Fig. 1. Schematic sketch to determine the rational fields of application of building machines

To establish machine-park with rational structure

Let us assume that the values V and L are independent probabilities. The acceptability of this assumption can be verified, since the next site is generally not known in advance by the work will have been finished at the actual site. Decision on the relocation of the machine is made by the leader of the company, either in ad-hoc manner or based on any technical-economical calculation. The decision depends on various random factors. If the assumption holds and the values V and L are between $v_1 - v_2$ and $l_1 - l_2$, then the probability of that the random value Ω — which depends on the values V and L — falls in the range of $v_1 - v_2$ and $l_1 - l_2$ can be expressed by the following relationship:

$$P(v_1 < V < v_2;\ l_1 < L < l_2) = \int_{v_1}^{v_2}\int_{l_1}^{l_2} f(v) f(L)\, dV\, dL =$$

$$= \int_{v_1}^{v_2} f(v)\, dV \cdot \int_{l_1}^{l_2} f(L)\, dL \tag{25}$$

where

$f(v)$ — the distribution function of in-situ work volumes,

$f(L)$ — the distribution function of the relocation distances.

To establish the probability by which the random value $\Omega(V, L)$ falls into more than one inner domains, the following series of equations can be given according to the sketch presented in Fig. 2:

$$P(i+3) = \int_{l_1}^{l_2} f(L)\, dL \left[\int_{0}^{v_1} f(V)\, dV + \frac{1}{2}\int_{v_4}^{v_2} f(V)\, dV \right] \tag{26}$$

$$P(i+2) = \int_{l_1}^{l_2} f(L)\, dL \left[\int_{0}^{v_3} f(V)\, dV + \frac{1}{2}\int_{v_3}^{v_4} f(V)\, dV \right] - P(i+3) \tag{27}$$

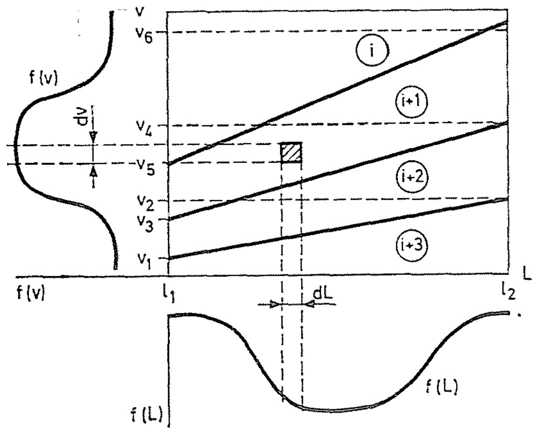

Fig. 2. Determination of the probabilities of each mechanization variants

$$P(i+1) = \int_{l_1}^{l_2} f(L)\, dL \left[\int_{0}^{V_6} f(V)\, dV + \frac{1}{2} \int_{V_4}^{V_5} f(V)\, dV \right] - [P(i+3) + P(i+2)] \quad (28)$$

$$P_i = 1 - [P(i+3) + P(i+2) + P(i+1)] \quad (29)$$

where

P_i, P_{i+1}, P_{i+2} are the probabilities by which the random values V and L fall into the range i, $i+1$, . . ., etc.

An example to illustrate the application of the method

Let us consider a concrete problem: the rational set-up of a hydraulic unibucket bagger is to be determined. These machines are controlled by one of the departments of Moscow Building Authority. By this department generally the earthworks of livings and public buildings and the loading of the trucks are made. It could be concluded by the analysis of the earthwork orders entered in the five years of existence of this department, that the values V and L are, in fact, independent random values.

From the probability processing of the variational series of L (selected from a sample of 700 random numbers) and V (selected from a sample of 500 random values) it could be concluded that the V values follow those below exponential distribution

$$f(V) = \lambda e^{-\lambda V} \quad (30)$$

where

λ — is the parameter of the distribution function ($\lambda = 1.59 \cdot 10^{-4}$).

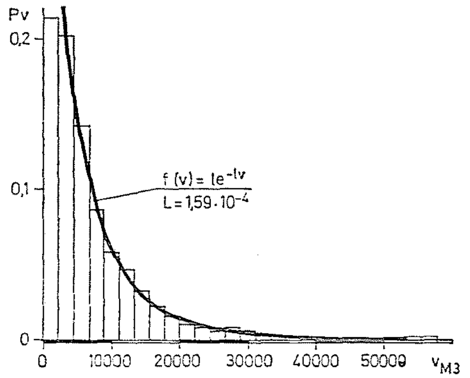

Fig. 3. Histogram and distribution function of earthwork volumes made by unibucket hydraulic baggers

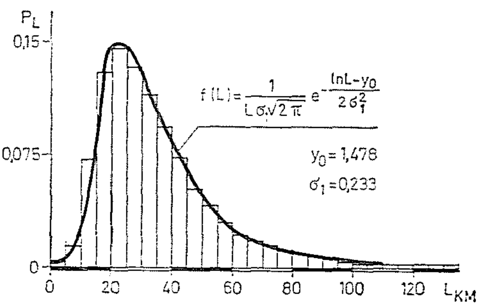

Fig. 4. Histogram and distribution function of relocation distances of unibucket hydraulic baggers

The acceptance of the hypothesis was tested against the Pearson's χ^2 test. The χ^2 value, obtained by the comparison of the empirical and theoretical frequencies (Fig. 3), could be accepted on a significant probabiltiy level, while 12.9 ($\chi^2 = 12.9$) $\gamma = 0.95$ and the theoretical value according to (3) is $\chi_t^2 = 21.9$. By this, the assumption whereas the correct distribution function had been selected is accepted, since $\chi_\Phi^2 < \chi_t^2$.

The random values L follow the lognormal distribution (Fig. 4).

$$f(L) = \frac{1}{L\sigma_l\sqrt{2\pi}} \cdot e^{-\frac{\ln L - y_0}{2\sigma_l^2}} \tag{31}$$

where

y_0 — the mean of the log values ($y_0 = 1.478$)

σ_l — the squared deviance of the log-values ($\sigma_l = 0.233$).

In the course of testing the hypothesis of the lognormal distribution, it could be concluded that $\chi^2 = 9.06$; $\chi_t^2 = 25$, on 5% probability level, i.e. the hypotheses set up in Fig. 4 are accepted by the statistical analysis.

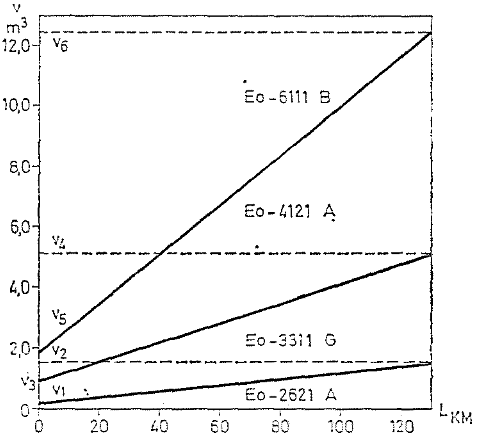

Fig. 5. The rational fields of application of unibucket hydraulic baggers

For 4 standard volumes (0.25 m^3, 0.4 m^3, 1.0 m^3 and 1.4 m^3) the application fields of the hydraulic unibucket bagger could be determined for specified work conditions (Fig. 5).

The specific reduced cost was calculated by Eq. (22). For the construction of isoefficiency lines Eq. (24) has been applied. For v_1 to v_6 and l_1, l_2, the following values have been obtained:

$v_1 = 13.7$ m^3, $v_2 = 1526$ m^3, $v_3 = 926$ m^3, $v_4 = 5297$ m^3, $v_5 = 1969$ m^3, $v_6 = 12634$ m^3,

$l_1 = 0$, $l_2 = 13$ km.

From to calculations — based on Eqs (26) to (29) — the following values could be obtained

$P_{e0-2621A} = 0.109$; $P_{e0-3311g} = 0.067$; $P_{e0-4121A} = 0.389$; $P_{e0-6111B} = 0.435$.

And this is in correspondence with the actual proportions for unibucket baggers of different types at the department.

The economical operation of the machines depends on various factors, even when they are used within their rational fields of application, e.g. on the average technical level, on the technology applied and on the qualification level of the operators, etc. Any of these factors affect the technical/economical characteristics examined in the determination of the efficiency of the machines.

Conclusion

A system of indices has been developed on the basis of technical/economical analysis, by which system the efficacy of the running machines Eq. (22) can be evaluated, the limits of their application can be derived Eq. (24) and the rational structure of the machine-park can also be determined. It has been verified that the machines operate under stochastic conditions.

Thus, the corresponding distribution functions can be derived and taken into consideration when the efficacy is evaluated. The method presented here can provide good basis for work organizatory decisions of building machines.

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