DEVELOPMENT OF A SYSTEM OF INDICES FOR EVALUATING THE EFFICIENCY OF UTILITY MACHINES

Khankelov T.K.[1,a]*, Mukhamedova N.B.[2,b], Kadirov A.G.[3,c], Aslanov N.R.[4,d], Gulyamov N.Sh.[5,e]

[1,2] Department of Engineering of Technological Machines, Tashkent State Transport University, Tashkent, Uzbekistan

[3] Department of Applied Mechanics, Tashkent State Transport University, Tashkent, Uzbekistan

[4,5] Department Of Automotive And Armored Vehicles, University of Public Safety of the Republic of Uzbekistan, Tashkent, Uzbekistan.

[a]xankelovt9@gmail.com, [b]nafisa8828muxamedova@gmail.com, [c]anvar_kadirov0604@mail.ru,

[d]naslonov1986@mail.ru, [e]normaxamat23@mail.ru

Abstract:

A system of indices for evaluating the efficiency of a utility machine is obtained on the basis of an integral index, which presents a specific reduced cost. The bases of the system of indices are such indices as energy intensity and material intensity. In addition, dependencies were developed for calculating the time of the garbage truck operating cycle, as an optimization criterion, and determining the main rational parameters of the garbage truck depending on operating conditions in the presence of an optimal target function. The choice of a rational solution is based on single-criteria optimization based on the analysis of one criterion - the duration of the garbage truck working cycle. The optimal mass of the container is determined by differentiating the duration of the cycle of the garbage truck to perform work operations based on the volumetric capacity of the container of the garbage truck.

Keywords: efficiency, unit cost, index, municipal solid waste, rational parameters, optimization, cycle duration.

Introduction:

An increase in urban population, rapid economic growth, and improvement of life in developing countries, as well as the pursuit of excessive profits for manufacturers through small-scale packaging of goods, have significantly accelerated the quantity and quality of solid waste generation, thus increasing its negative impact on the environment [1, pp.27-28; 2, pp.1-8; 3, pp.1-9; 4, pp. 271-277; 5, pp.45-54].

The development strategy of New Uzbekistan for the period 2022-2026 highlights the implementation of the following tasks "Improving the system for assessing environmental pollution, monitoring the environment, and predicting the degree of environmental pollution. Information support of the state environmental control body, monitoring of the state of pollution sources and their impact on the environment" and "Increasing the percentage of collection of municipal solid waste up to 100 percent" [6, pp.15-17]. When performing the above tasks, research aimed at developing a system of indices for evaluating the efficiency of machines for collecting and transporting solid waste is relevant; it will increase the efficiency of their use and select a rational option for a utility machine based on its operating conditions.

The issues of physical modeling of the working processes of garbage trucks are considered in the publications of G.M. Belotserkovsky. Based on the principles and methods of the theory of similarity and modeling, he developed a rheological model and similarity criteria for the processes of filling garbage in the body of a garbage truck with solid household waste [7, pp.73-78].

The following scientists were engaged in improving the calculation of garbage trucks: Karaban G.L., Balovnev V.I., Zasov I.A., Lifshits B.A. They developed a methodology for calculating the main parameters of garbage trucks and designed some components of the loading manipulator [8, pp.23-30].

Publications by A.A. Domnitsky are mainly devoted to improving the design of garbage trucks. In [9], he proposed a form of a new, more durable body structure and a way to improve the maintenance system of a garbage truck.

R.V. Kargin and V.I. Zhigulsky studied the issues of reliability of garbage trucks. They proposed a methodology for selecting and substantiating the reliability indices of a garbage truck [10, pp.37-40].

The studies by P.G. Karpukhin are devoted to the determination of the carrying capacity of machines for the collection and transportation of waste. A method for establishing the optimal value of the carrying capacity of a machine for the collection and removal of municipal solid waste based on the theoretical distribution function of the solid waste transportation distance was proposed [11].

Evaluation of the efficiency of garbage trucks by criteria analysis of the main technical and operational indices using the methods of similarity theory and modeling based on operating conditions was considered by V.I. Balovnev [12, 13].

Research conducted by A.B. Ermilov [14] is devoted to the calculation and design of special vehicles for the collection and removal of solid domestic waste.

The studies by M.S. Altunina deal with the issues of improving the systems of maintenance and repair of a garbage truck [15, pp.298-301].

Research works by F.B. Teshome are devoted to the calculation of the loading manipulator, in particular, to the method of determining the water pressure in the hydraulic cylinders in transients [16, pp.18-31].

Articles by T.K. Khankelov, N.B. Mukhamedova, S.I. Komilov, and others are devoted to the analysis of the designs of garbage trucks, their choice based on operating conditions [17, pp.477-479; 18, pp. 20184-20187; 19, pp. 32-34; 20, pp. 1087-1092].

Despite the large number of studies conducted by scientists, the problem of developing a methodology for assessing the efficiency of garbage trucks remains relevant.

The modern market of construction, road, and municipal equipment provides the work superintendent with a wide choice of machines of various nomenclature, size, and purpose. Construction is equipped with automated complexes, multi-purpose equipment, manipulators, and robots. This leads to an increase in the options for machines and parameters of working bodies that ensure optimal performance of work. Solutions that are far from optimal ones lead to significant losses.

The methodology for evaluating the effectiveness and technical level of road and municipal equipment is today an important tool for the work superintendent that contributes to solving problems related to obtaining high profits.

Optimization methods based on the criteria and indices of the cost of work, give the most complete assessment of efficiency, taking into account specific operational factors. However, in market conditions, the calculation of the efficiency of equipment based on the cost of work in the future presents certain difficulties. The cost of operating the machinery, or operating costs, is a trade secret. The cost of machines on the market to a greater extent reflects market demand than the quality of equipment.

In the context of limited commercial information on cost and rational costs, the efficiency and rational parameters of machines at the stage of their manufacture can be established by analyzing their technical and operational indices. To determine the technical efficiency of machines, the corresponding technical and operational indices are calculated on the basis of known technical parameters and operating conditions of machines. These are such indices as specific energy intensity (kVt ·hr/m^3), material consumption (t·hr/m^3), productivity (m^3/hr), output per worker (m^3/m·hr) and a number of generalized indices derived from the calculated ones.

The choice of a rational solution is based on single-criteria optimization based on the analysis of one criterion [21, pp. 20-31; 22, pp. 349-354; 23, pp. 274-276; 24, pp. 97-102; 25, 25, pp. 1-6]. Multi-criteria optimization under the action of several criteria, including contradictory ones in the sense of Poreto, is not considered in the article.

Materials and methods of research.

A comprehensive analysis of the effectiveness of machinery requires the presence of various indices that determine the effect obtained, depending on the goals facing the superintendent of work, using various types of equipment in different operating conditions. The system of target indices linked into a single hierarchical structure can be obtained based on the analysis of such an integral index as the reduced unit costs [26, pp.18-24]:

$$\mathrm{Z_{sp}} = \frac{\mathrm{Z_{red}}}{\mathrm{P}}\text{, som/unit.product,} \quad (1)$$

where $\mathrm{Z_{red}}$ are the reduced costs per hour of operation, som/hr;

P is the hourly operational productivity, unit. product/hr.

The latter is determined through the hourly technical productivity P_t

$$P = k_t \cdot P_t, \tag{2}$$

where k_t is the machine utilization rate over time.

The value of the reduced costs Z_{red} is determined by the following formula:

$$Z_{red} = C + kE_n \tag{3}$$

where C are the operating costs, reduced to the hour of operation of the machine, som;
k are the capital investments, som; E_n is the normative coefficient of efficiency, determined by the value of the credit interest in fractions of a unit ($E_n = 0{,}2 \div 0{,}8$).

The resulting systems of criteria are based on the analysis of the machine as a complex system and the allocation of costs for each of the subsystems. The machine is divided into a number of subsystems, taking into account the connection between them and the characteristics of the input, output and restrictions. The system includes the following subsystems:
- energy subsystem (engine, environmental equipment of the engine, and other elements);
- technological subsystem (working equipment, machine frame, mover);
- life support and control subsystem (cabin, life support equipment, computer and hydraulic equipment);
- service personnel (operators and employees of auxiliary services).

The reduced costs are determined by expense items separately for each of the main subsystems of the machine: for the power supply subsystem, the costs are proportional to the set engine power *N* in *kVt*; for the technological subsystem, the costs are proportional to the mass of the machine *m* in *kg;* for the life support subsystem, the costs do not directly depend on *N* and *m*; the costs for the operator and maintenance personnel can be taken proportional to the mass of the machine and the number of workers servicing the machine, n_p.

Capital investments for new equipment k consist of the costs for the purchase of equipment (wholesale price, leasing, dealer costs, transportation, and installation costs), and the costs for the operation of equipment (new facilities, equipment, insurance, etc.).

Referred to an hour of work, these cost items can be determined by the cost of the main subsystems of the machine:

$$k = a'_0 + a'_1 \cdot N + a'_2 \cdot m, \tag{4}$$

where a'_0 is the dimensional coefficient characterizing capital investments in the operator's life support subsystem, which do not directly depend on the power and mass of the machine, som/hr;

a'_1 is the coefficient that accounts for capital investments in the energy subsystem, proportional to engine power, som/(*kVt·hr);*

a'_2 is the coefficient that accounts for capital investments in the technological subsystem, proportional to the mass of the machine, som/*(κg·hr)*.

Current operating costs (for raw materials, management, wages, deductions for renovation, maintenance and repair, and relocation costs) are proportional to the mass of the machine, *m*. The cost of energy (fuel) and lubricants consumed is proportional to the power of the machine *N*. Current costs, reduced to the hour of work and calculated for each subsystem, can be determined by the following formula:

$$C = a''_0 + a''_1 \cdot N + a''_2 \cdot m + a''_3 \cdot \text{п}_\text{p} \cdot m, \tag{5}$$

where a''_0 is the dimensional coefficient characterizing the operating costs for the life support and control subsystem, som/hr; a''_1 is the dimensional coefficient characterizing the operating costs of the energy subsystem, som/(*kVt·hr*); a''_2 is the dimensional coefficient characterizing the operating costs of the technological subsystem, som/(*kg·hr*); a''_3 is the dimensional coefficient characterizing the operating costs for wages, depending on the number of service personnel and the mass of the machine, som/(*m/κg·hr*); n_p is the number of operators and workers servicing the equipment, pers.

The efficiency of mechanization of production within the framework of the national economy is generally estimated by the index of reduced unit costs Z_{sp} based on dependencies (1) and (3).

For building and other organizations operating machinery, the efficiency of using machines is evaluated according to criterion C_{sp} - the unit operating cost or the cost of work, measured in som/unit.product:

$$C_{sp} = C/P, \tag{6}$$

or after substitution of expression (5) into (6) and some transformations:

$$C_{sp} = a''_0/P + a''_1 \cdot N_{sp} + a''_2 \cdot m_{sp} + a''_3 \cdot m/n_{prod}\ , \tag{7}$$

where N_{sp} is the specific energy consumption of the working process of the machine, kVt/unit.cap, $N_{sp} = N/P$; m_{sp} is the specific material consumption of the working process of the machine, *kg/unit* of productivity, $m_{sp} = m/P$; n_{prod} is the output per worker, showing the units of productivity per worker, $n_{prod} = P/n_w$

The coefficients characterizing the operating costs, $a''_0, a''_1, a''_2, a''_3$ in equations (5) and (7) can be determined based on the analysis of statistical information on operating costs for each of the subsystems of the machine per unit of time, referred to the characteristics of the subsystem:

$a_0'' = \frac{\sum E_0''}{\sum T}$, som/hr; $a_1'' = \frac{\sum E_1''}{N \cdot \sum T}$, som/(к$Vt \cdot hr$); $a_2'' = \frac{\sum E_2''}{m \cdot \sum T}$, kVt/(к$g \cdot hr$);

$a_2'' = \frac{\sum E_3''}{\sum п_р \cdot m \cdot \sum T}$, som/($hum.$· к$g \cdot hr$).

where $\sum E_0''$ are the operating costs for life safety, computers, management for the period of operation, som; $\sum E_1''$ are the operating costs for the energy subsystem of the machine (fuel, lubricant, etc.) for the period of operation, som; $\sum E_2''$ are the operating costs for the technological subsystem of the machine (raw materials, technical service, repair, relocation, etc.), som; $\sum E_3''$ are the operating costs for the wages of service personnel, som; $\sum T$ is machine operation time, hour.

Productivity P is an important component of most performance indices. Performance is determined either experimentally or theoretically. In this case, the compared machines must operate under the same operating conditions.

Expression C_{sp} (7) is an integral index of evaluation under operating conditions. The index is used as a target function for the analysis and evaluation of the technical and economic efficiency of the use of machines.

Expression C_{sp} includes generalized and specific indices. The integral index can be written as:

$$C_{sp} = \frac{N_{sp}}{P_{sp} \cdot n_{prod}} \cdot k_{red} \ , \qquad (8)$$

where k_{red} is the coefficient of reduction of the conditional generalized index $\frac{N_{sp}}{P_{sp} \cdot n_{prod}}$ to the interval one C_{sp}, in this case, to specific operating costs. Expression k_{sp} is a polynomial that remains in the brackets of expression (7) after factoring the corresponding indices.

P_{sp} is the specific productivity,

$P_{sp} = P/m$.

The analysis of expressions for calculating the specific reduced costs in the form of a polynomial or the product of a polynomial by the corresponding factor makes it possible to form a number of interrelated ranked indices for evaluating the efficiency of using machinery and its technical level, depending on the type and purpose, see Table.

System of indices (criteria) for evaluating the effectiveness and optimal use of machinery

1st group. Technical and economic indices (measured in cost units). Cost of work $C_{sp,}$ or operating costs

№	Name and purpose of the index	Form of recording	Unit of mea-surement	Optimization condition
1	2	3	4	5
1	Evaluation of efficiency in terms of operating costs for the entire system.	$C_{sp} = \frac{a_o''}{P} + a_1'' \cdot N_{sp} + a_2'' \cdot m_{sp} + a_3'' \cdot \frac{n_w m}{P}$	$\frac{som}{un.prod.}$	min
2	Evaluation by operating costs for energy and technological subsystems and wages.	$C_{sp.s} = a_1'' \cdot N_{sp} + a_2'' \cdot m_{sp} + a_3'' \cdot \frac{n_w m}{P}$	$\frac{som}{un.prod.}$	min
3	Evaluation by operating costs for the energy and technological subsystems.	$C_{sp} = a_1'' \cdot N_{sp} + a_2'' \cdot m_{sp}$	$\frac{som}{un.prod.}$	min
4	Evaluation of operating costs for the energy subsystem.	$C_{sp.N} = a_1'' \cdot N_{sp}$	$\frac{som}{un.prod.}$	min
5	Evaluation of operating costs for the technological subsystem.	$C_{sp.m} = a_2'' \cdot m_{sp}$	$\frac{som}{un.prod.}$	min
6	Evaluation by operating costs for labor resources.	$C_{sp.c} = a_3'' \cdot \frac{n_w m}{P}$	$\frac{som}{un.prod.}$	min
7	Evaluation by operating costs for management and life support.	$C_{sp.en} = \frac{a_o''}{P}$	$\frac{som}{un.prod.}$	min
2nd group. Technical and operational indices (measured in physical units)				
1	2	3	4	5
8	Evaluation of efficiency by reduction in energy, material, and labor costs	$P_{Nmn} = \frac{N_{sp}}{P_{sp} \cdot n_{prod}}$	$\frac{кVt \cdot hr}{un.prod.}$	min

9	Evaluation of efficiency by reduction in energy and material costs	$P_{Nm} = \frac{N_{уд}}{P_{уд}}$	$\frac{кVt \cdot h}{un. cap.}$	min
10	Specific energy intensity	$N_{sp} = \frac{N}{P}$	$\frac{кVt \cdot h}{un. prod.}$	min
11	Specific material consumption	$m_{sp} = \frac{m}{P}$	$\frac{кg}{un. cap.}$	min
12	Specific productivity	$P_{sp} = \frac{P}{m}$	$\frac{un. cap.}{кg}$	max
13	Production per person	$n_{prod} = \frac{P}{n_w}$	$\frac{un. cap.}{hum.}$	max
14	Performance	$P = \frac{q}{t_{ts}}$	$\frac{un. prod.}{un. time.}$	max
15	Energy intensity of the machine (system)	$N_{en} = \frac{N}{m}$	$\frac{кVt}{кg}$	opt.
16	Cycle time	$T_{cycle} = \sum t_i$	C	min
17	Efficiency	ɳ	-	max
18	Machine utilization by time	K_u	-	max
19	Fleet availability	k_r	-	max
20	Individual technical parameters	N, m, I, etc.	-	opt.

<u>The first group of indices includes technical and economic criteria.</u> This group is the main one and allows us to calculate the effect in units of cost per unit of output. A number of indices are formed depending on the index of expense items taken into account in the calculation.

Operating costs C_{sp} (7) are measured in som/un. prod. The exponent is a polynomial of four terms. In the case under consideration, it takes into account the costs for four main items of expenditure: ensuring safety and control, energy, material, and labor costs.

Operating costs $C_{sp\,Nmn}$ for three expense items: energy, material, and labor costs in som/un. prod. are:

$$C_{sp\,Nmn} = a_1'' \cdot N_{sp} + a_2'' \cdot m_{sp} + a_3'' \cdot m/n_{prod}, \qquad (9)$$

Operating costs $C_{sp.Nm}$ for two expense items: energy and material costs in som/ un. prod. are:

$$C_{sp\,Nmn} = a''_1 \cdot N_{sp} + a''_2 \cdot m_{sp}, \tag{10}$$

Specific costs can be considered separately for each item of expenditure: energy costs $C_{sp\,N} = a''_1 \cdot N_{sp}$, material costs $C_{sp\,m} = a''_2 \cdot m_{sp}$, labor costs $C_{sp.red} = a''_3 \cdot m/n_{prod}$, measured in som/un.prod.

This group also includes the geometric mean costs for the main items of expenditure, expressed in un. price/un. prod. The geometric mean value of operating costs for the three main items of expenditure can be calculated based on the following expression:

$$C_{sp\,Nmn\;av.} = \left(\frac{N_{sp} a''_1 a''_2 a''_3}{P_{sp} \cdot n_{prod}}\right)^{1/3} \tag{11}$$

The geometric mean value of operating costs for the energy and technological subsystems of the machine has the following form:

$$C_{sp\,Nmn\;cp} = \left(\frac{N_{sp} a''_1 a''_2}{P_{sp}}\right)^{1/2}. \tag{12}$$

The geometric mean of operating costs for the main subsystems of the machine can be used for a preliminary assessment of machinery. The main group of indices of the efficiency of using the machine is the indices of the first group, representing the reduced unit costs for the main subsystems of the machine. Depending on the goals set, these indices are Z_{sp}, C_{sp}, etc. The indices are measured in cost units - in som /un.prod. The use of indices based on their cost measurement presents certain difficulties. The cost of operating expenses in market conditions is a trade secret. The cost of a machine on the market largely reflects its market demand.

To predict efficiency, these quantities can be used to a limited extent. Evaluation of the effectiveness of machinery objects during design and operation, when information on financial costs is not available, is conveniently conducted according to generalized indices in physical units of measurement (kg, m, sec, etc.).

The second group of indices includes technical and operational criteria. They are measured in physical units and characterize the degree of technical perfection of the machine under appropriate operating conditions, taking into account the goals set for the superintendent of work. This group consists of a number of generalized, relative, and particular indices.

Generalized $N_{Nm} = \frac{N_{sp}}{P_{sp} \cdot n_{prod}}$ characterizes energy, material, and labor resources per unit of productivity in physical units. The value of N_{Nm} has an objective technical and economic meaning and shows how many units of specific energy intensity N_{sp} are accounted for per unit of specific productivity Π_{sp} and unit of output per worker. The best machine has the minimum value of index N_{Nm}.

The generalized index N_{Nm} has a similar structure.

$$N_{Nm} = \frac{N_{sp}}{P_{sp}}.$$

It characterizes the energy and material costs in physical units per unit of specific productivity. The value of P_{Nm} shows how many units of specific energy intensity are accounted for per unit of specific productivity.

The best machine has the minimum value of index N_{Nm}.

Specific energy intensity

$$N_{sp} = \frac{N}{P}$$

characterizes the cost of energy per unit of productivity, the best machine has the minimum value of the index.

Specific material consumption

$$m_{sp} = \frac{m}{P}$$

characterizes material costs per unit of productivity. The best machine has the minimum value of the index.

Specific productivity

$$P_{sp} = \frac{P}{m}$$

is the inverse of m_{sp}, and characterizes the performance of the machine per unit mass. The best machine has the maximum value of the index.

The energy intensity index of the machine

$$N_{ener} = \frac{P}{m}$$

characterizes the energy costs per unit mass. The best machine has the optimal value of the index under given operating conditions.

Machine performance (technical and operational)

$$P = \frac{q}{t_{cycle}}$$

determines the number of units of production per unit of time.

The output per worker

$$n_{prod} = \frac{\mathrm{P}}{\mathrm{n_w}}$$

characterizes the number of units of productivity per worker.

Then, there are partial indices of individual units of the machine and individual working operations: $\mathrm{t_{ts}}$ is the time of the working cycle, $\mathrm{t_i}$ is the time of a single operation of the cycle, $\mathrm{k_{use}}$ is the utilization rate of the machine, which characterizes its reliability, η is the efficiency of the machine and individual units.

The index for evaluating the efficiency of the machine is chosen depending on the goals set by the superintendent of work. Thus, the efficiency in terms of energy and material costs in physical units of measurement is determined on the basis of index N_{Nm}. Efficiency in reducing the time to perform work can be evaluated in terms of cycle time $\mathrm{t_{ts}}$ or productivity P. An analysis of the generalized indices shows that a highly reliable machine with technical parameters determined by calculation on the basis of known provisions can, for most cases, be used in such operating conditions, where it can give the greatest effect on the set target index. The parameters of operating conditions in this case can be established based on the solution to the inverse problem.

The analysis of the considered indices of the system makes it possible to emphasize a number of conclusions.

The performance index from the system of indices should be selected based on the goals set by the work superintendent (financial savings, reduction of energy and material resources, reduction of time of work completion, etc.).

The efficiency of using various types of equipment under operating conditions should be determined by analyzing technical and economic indices $\mathrm{C_{sp}}$, measured in un./price (see Table).

The technical efficiency of machines should be evaluated according to technical and operational indices varying in physical units of measurement (see Table).

The value of the efficiency index depends on the technical parameters of the machine and operating conditions.

The optimal numerical values of the machine parameters, such as energy intensity *N/m*, power *N*, mass *m* and others, are determined by the nature of the target function and operating conditions.

Effectiveness indices of the use of the machine in cost units of measurements $\mathrm{C_{уд}}$ are the main ones, however, the difficulties of their use in market conditions make it possible to recommend an evaluation of efficiency based on generalized indices in physical units of measurement (kVt, kg, m, sec, etc.). As a generalized index, P_{Nm} should be used, which is a compromise of two separate indices of specific energy consumption N_{sp} or specific productivity P_{sp} or specific material consumption m_{sp}.

The optimal parameters or solutions established by one of the performance criteria may not coincide with those established by other target criteria.

A highly reliable machine with rational technical parameters for most cases can be used in such operating conditions where it shows the greatest technical and economic effect.

The efficiency of using the machine and its choice in terms of cost can be evaluated in two stages - by dividing the search area into parts. In the first stage, it is necessary to optimize the choice of machine parameters according to technical and operational indices that have physical units of measurement P_{Nm}. In the second stage, among the technically optimal machines, the one acceptable in terms of cost should be chosen.

Productivity is one of the important characteristics of establishing rational parameters of machinery in operating conditions. In the structure of the system of criteria, performance is determined experimentally or theoretically. Experimental determination of the productivity of machines to be compared is conducted under the same operating conditions according to state standards.

Consider the application of the developed system of indices in the example of a garbage truck.

A garbage truck, as a sanitary-ecological machine, must collect and remove municipal waste in the shortest possible time intervals. As an optimization criterion for this case, it is appropriate to use the performance of the garbage truck. This index will allow us to choose a machine that will ensure the removal of garbage at maximum performance in the shortest time. In this case, the collection and removal of garbage are ensured in accordance with sanitary and economic requirements.

Dependency for calculating the time of the working cycle of the garbage truck as an optimization criterion is formed.

The performance of the garbage truck depends on the geometric capacity of the trick body V measured in m^3 and the duration of the working cycle in *sec*. Productivity is determined by the formula derived by Prof. G.L. Karaban (8):

$$P = \frac{3600 \cdot k_l \cdot k_u \cdot V}{t_{\sum cycle}}, m^3/hr, \quad (13)$$

where V is the geometric capacity of the truck body, m^3; k_l is the body load factor; k_u is the utilization factor of the garbage truck over time; t_(∑cycle) is the total time of the working cycle, *sec*.

The total cycle time is determined by the following formula:

$$t_{\sum cycle} = t_l + t_{pr.l} + t_m + t_{mov} + t_{tr} + t_{id} + t_{pr.tr,} \quad sek, \quad (14)$$

where t_l is the average time of the main operation for loading the truck body, sec; $t_{pr.l}$ is the time for preparatory final operations to capture the container, sec; t_m is the time for maneuvering when approaching the container, sec; t_{mov} is the average time for a garbage truck to move from container to container within a block, sec; t_{tr} is the average time for garbage transportation to the site of removal, sec; t_{id} is the average time for the machine to return to its original state, sec; $t_{pr.tr}$ are the preparatory and final operations during transportation, sec.

Formula (14) can be reduced to the following form (for $t_{tr} \approx t_{id}$):

$$P = \frac{3600 \cdot k_l \cdot k_u \cdot V}{k_{aux.l} \cdot t_3 + k_{aux.tr} \cdot t_{tr}}, m^3/hr, \quad (15)$$

where $k_{aux.l}$) is a coefficient that takes into account the duration of auxiliary operations during loading ($k_{pr.l}, t_m, t_{mov}$); $k_{aux.l}$ is the coefficient that takes into account the duration of auxiliary operations $t_{aux.tr}$ when unloading and transporting garbage.

The values of coefficients $k_{aux.l}$ and $k_{aux.tr}$ are experimental values and determined by the following formulas:

$$k_{aux.l} = 1 + \frac{t_{pr.l} + t_m + t_{mov}}{t_l};$$

$$k_{aux.l} = 1 + \frac{t_{pr.tr}}{t_{tr} + t_{id}}.$$

Expressing in formula (15) the time for the loading operation (t_l), the transportation operation and the return for a new load of garbage (t_{tr}) by technical and operational parameters of the garbage truck, we obtain:

$$P = \frac{K_l \cdot V}{k_1 \frac{m_{con}}{m} + k_2 \frac{f \cdot m \cdot l_{mp}}{N}}, m^3/hr, \quad (16)$$

where $k_1 = f\left(k_{pr.l}\ h_{l,}\ V_l\right), c;\ k_2 = \frac{k_{pr.tr} \cdot k_c \cdot g}{\eta \cdot (1-\delta) \cdot k_{l.en}}, m/s^2\ k_3 = 3600 k_l k_{u,}$

V- geometric capacity of the body, m^3;

m_{con}- mass capacity of garbage in the yard container, кg;

f- coefficient of resistance to the movement of the garbage truck;

l_{tr}- distance of garbage transportation to the site of disposal or to the place of reloading into a transport garbage truck, m;

N- engine power of the machine, Vt;

h_l- lifting height of the container when loading the body, m;

v_l- container lifting velocity, m/sec;

k_l- coefficient that accounts for the movement of the garbage truck with load and return without load;

g - free fall acceleration, g = 9,81 m/sec^2 ;

η- transmission efficiency;

δ- average coefficient of slipping;

$k_{l.en}$- average engine load factor.

Analysis (16) shows that productivity reaches the maximum value at the minimal value of the denominator - cycle time. The denominator has a minimum at a certain value of the mass capacity of the garbage truck, m.

The garbage truck has one engine with power N.

When collecting and loading garbage, the speed of the garbage truck is minimal; in order to use its power, it must be loaded as much as possible, i.e. the reduction in t_l is provided by the increase in *m*.

During transportation, on the contrary, the speed ϑ is maximal and to use the engine power, m should be reduced with an increase in ϑ.

The graph of function (16) depending on the mass capacity of the body and the power of the engine of the base chassis *N* (at I_{tr}= 5 km, $k_{pr.l}$ =60) is shown in Fig.1.

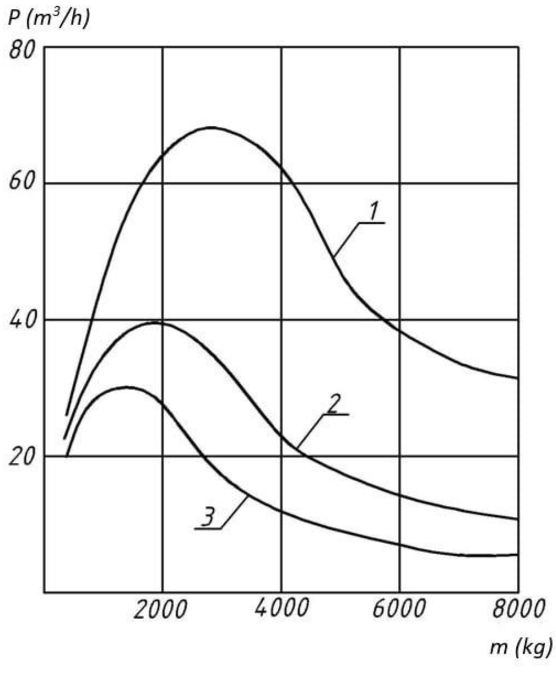

Fig. 1. Dependence of the operational performance P of the garbage truck on the mass capacity of the truck body m and the engine power N of the base chassis at l_{tr} = 5 km: 1-N =60 kVt; 2-N=90 kVt; 3-N=135 kVt

The graph in Fig. 2 shows the dependence of function (16) on the mass capacity of the truck body m and the distance of transportation of garbage l_{tr} (at N= 135 kVt, $k_{pr.l}$=60).

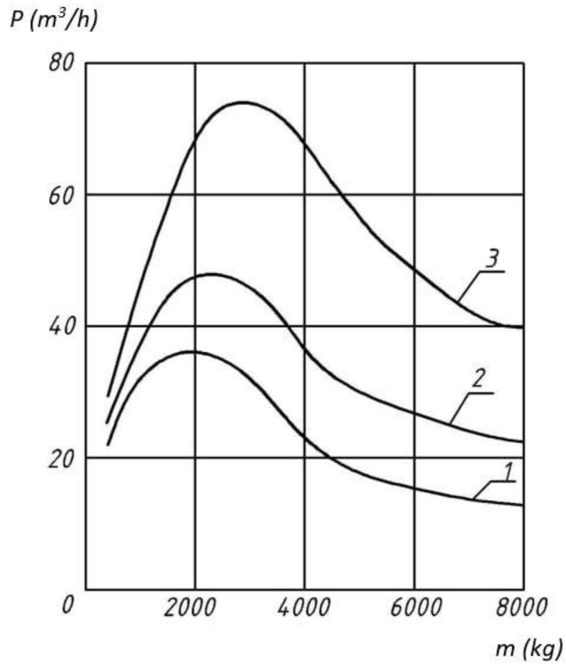

Fig. 2. Dependence of the operational performance P of the garbage truck on the mass capacity of the truck body m and the transportation distance l_{tr}

at power N=135 kVt:1- $l_{tr} = 5$ km; 2- $l_{tr} = 10$ km; 3- $l_{tr} = 20$ km

The optimal value of the mass is determined by equating the first derivative of the denominator in formula (12) to zero:

$$\frac{d}{dm}\left(k_1\frac{m_{con}}{m} + k_2\frac{f \cdot l_{tr} \cdot m}{N}\right) = 0.$$

After differentiation we have

$$-k_1\frac{m_{con}}{m^2} + k_2\frac{f \cdot l_{tr}}{N} = 0.$$

From this expression, the optimal value of m is determined, at which the performance has the maximum value.

$$k_1\frac{m_{con}}{m^2} = k_2\frac{f \cdot l_{tr}}{N},$$ therefore,

$$m^2 = \frac{k_1 \cdot m_{con} \cdot N}{k_2 \cdot f \cdot l_{tr}},$$ or

$$m_{opt} = \left(\frac{k_1 \cdot m_{con} \cdot N}{k_2 \cdot f \cdot l_{tr}}\right)^{1/2}$$, кg.

Introducing k_1 and k_2

$$m_{opt} = \left(\frac{k_{pr.l} \cdot h_l \cdot \eta \cdot (1-\delta) \cdot k_{l.en} \cdot m_{con} \cdot N}{V_l \cdot k_{aux.tr} \cdot k_c \cdot g \cdot f \cdot l_{tr}}\right)^{1/2}, \text{кg}. \quad (17)$$

The analysis of formula (17) shows that the optimal value of m_{opt} of the mass capacity of the truck body depends on a number of factors.

The value of m_{opt} increases with increasing power N and decreases with an increase in the transportation distance l_{tr} and the coefficient of resistance to the movement of the machine l. In addition, the more time for auxiliary operations $k_{aux.l}$ during loading, the greater m_{opt}. Therefore, it is important to reduce the time for auxiliary operations.

Based on formula (17), dependencies $m_{opt} = f(l_{tr})$ and $N_{opt} = f(m_{opt})$ can be established.

Formula (17) is transformed to the following form:

$$m_{opt} = \frac{k \cdot N}{k_{con} \cdot l_{tr}}, \text{кg},$$

where $$k = \frac{k_{aux.l} \cdot h_l \cdot \eta \cdot (1-\delta) \cdot k_{l.en}}{V_l \cdot k_{aux.tr} \cdot k_l \cdot g \cdot f}, sek^3/m$$

k_{con} is the ratio of the mass capacity of the body to the mass capacity of the yard container m_{con}; $k_{con} = \frac{m}{m_{con}} = 15 - 27$.

The dependence of the optimal value of the load capacity (17) m_{opt} on the transportation distance l_{tr} and the engine power N of the base machine is given in Fig. 3.

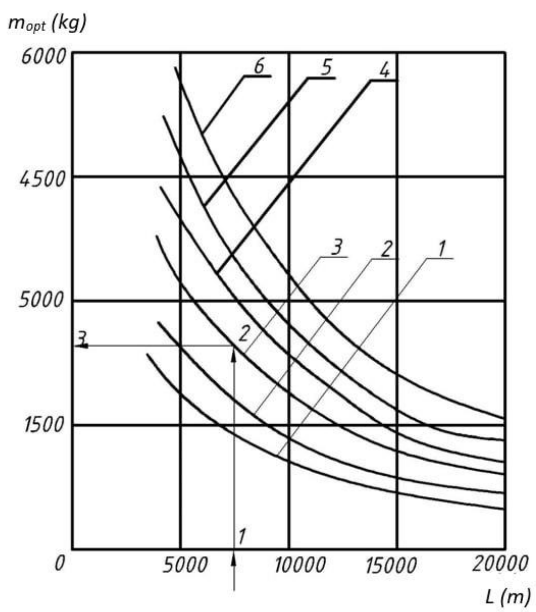

Fig. 3. Dependence of the optimal value of the mass capacity of the body m_{opt} on the distance of

transportation of waste l_{tr} and the engine power N of the base machine: 1- N=60 kVt; 2- N=75 kVt; 3- N=90 kVt; 4- N=115 kVt; 5- N=135 kVt; 6- N=150 kVt

Based on (17), the rational value of power N_{rat} is determined depending on m_{opt}:

$$N = \frac{k_{con}}{k} l_{tr} \cdot m_{\text{opt},} Vt. \quad (18)$$

The graph of function (18) depending on the mass capacity of the truck body m_{opt} and the transportation distance l_{tr} is given in Fig. 4.

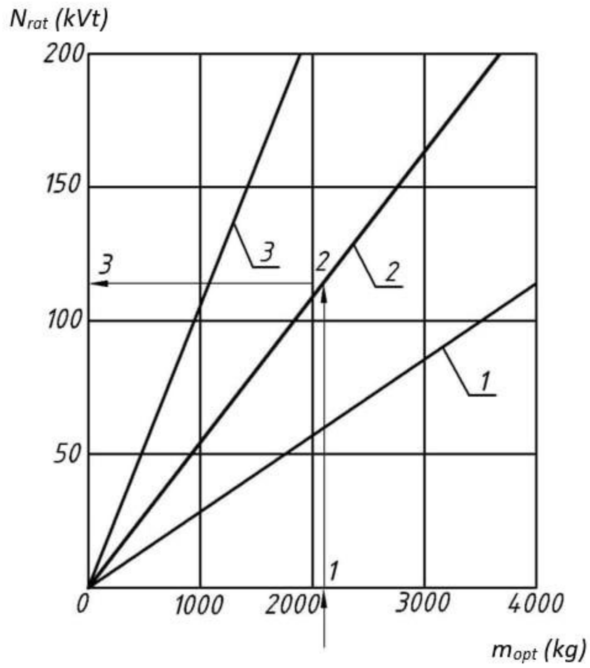

Fig. 4. Dependence of the rational engine power of the base machine N_{rat} on the optimal mass capacity of the garbage truck body m_{opt} and the transportation distance of waste l_{tr}: 1- $l_{tr} = 5$ km; 2- $l_{tr} = 10$ km; 3- $l_{tr} = 20$ km

The methodology is based on minimizing the time for performing waste collection and disposal operations or maximizing the performance of a garbage truck.

First, a machine is selected that can operate in conditions of travel on intra-block roads, in a cramped working area.

Then, according to the given average transportation distance l_{tr} (this value is determined by the distance from the waste collection point to the site of their disposal), the optimal mass capacity of the truck body is selected. To do this, on the graph in Fig. 3, point 1 is plotted on the horizontal axis with the required l_{tr}. A vertical line is drawn to point 2 - the point of intersection with the curve of the specified engine power (of the exploited machine). Then a horizontal line is drawn from point 2 until it intersects with the vertical coordinate axis at point 3. This point gives the value of the optimal mass capacity of the truck body m_{opt}. From the operating garbage trucks, the one is selected with m having the closest value to m_{opt}. The value of m_{opt} for a given l_{tr} is also determined by formula (17).

The value of rational power is checked, as shown in the graph (Fig. 4). Point 1 is marked on the horizontal axis by the value of m_{opt}, obtained in the graph in Fig. 3. Point 3 gives the value of N rational. A garbage truck with a capacity that best matches the capacity of N_{rat} is selected. Rational power can be determined by calculation using formula (18).

From the existing garbage trucks, one is selected for which parameters m and N most closely match the calculated ones m_{opt} and N_{rat}, respectively.

Conclusions:

1. A machine with rational parameters must be determined based on an analysis of performance indices, taking into account operating conditions. The system of criteria is given in the table.
2. Optimization criteria, or performance indices, on the basis of the analysis of which a rational decision is made, are selected with an account for the goals set by the work superintendent (reducing production time, saving energy costs, saving labor costs, reducing the cost of works, and others),
3. In the structure of the enterprise of technical service and production of equipment, it is advisable to organize a structure that should:

a) process information about the operating conditions of manufactured and sold equipment;
b) give recommendations to buyers of equipment on the most rational machines necessary for the effective performance of work in the conditions of operation of the equipment;
c) recommend introducing changes in the design of the machine that would increase its efficiency.

References

[1] Khankelov T., Askarhodzhaev T., Mukhamedova N. 2020. Determination of key parameters of a device for sorting municipal solid waste. (Journal of Critical Reviews. Vol.7), Issue: 4, pp.27-28.

[2] Khankelov T.K., Maksudov Z.T., Mukhamedova N.B., Tursunov Sh.S. Crushing and screening complex for the production of compost from organic components of municipal solid waste // II International Scientific Conference «Construction Mechanics, Hydraulics and Water Resources Engineering» (CONMECHYDRO-2021), April 1-3, Tashkent, Uzbekistan, 2021,pp.1-8.

[3] Kosimbetov, B., Khankelov T. Use of advanced technological methods for the recovery of cone crusher equipment // II International Scientific Conference «Construction Mechanics, Hydraulics and Water Resources Engineering» (CONMECHYDRO-2021), April 1-3, Tashkent, Uzbekistan, 2021, pp.1-9.

[4] Hongmei Lu., Roman Sidortsov. 2019 Sorting a problem: A co-production approach to household waste management in Shanghai, China. (Waste Management 95), pp.271-277.

[5] Gonopolskiy A.M., Zinyakina E.V., Denisova T.V. 2017 Waste cutter roller. (Bulletin of SUSU. Series "Food and Biotechnology". Vol.5), No. 1, p.45-54.

[6] Decree of the President of the Republic of Uzbekistan dated January 28, 2022 No. PP-60 “On the Development Strategy of New Uzbekistan for 2022-2026”. P.15-17.

[7] Belotserkovsky G.M. Rheological model and similarity criteria for the processes of filling the body of garbage trucks with solid household waste. -M., Sci. works / ACS, vol. 154, 1978, p. 73-78.

[8] Karaban G. L. Machines for the municipal economy / G.L. Karaban, V.I. Balovnev, I.A. Zasov, B.A. Lifshits. - M.: Mashinostroenie, 1988. - 272 p.

[9] Domnitsky A. A. Improving the efficiency of body garbage trucks by improving the design of the manipulator and the maintenance system: Dis. ... Cand. Tech. Sci.: 05.05.04. - Novocherkassk, 2007. - 159 p.

[10] Kargin R.V., Zhigulsky V.I. Reliability of body garbage trucks / Truck. - 2012. - No. 2. - P. 37-40.

[11] Karpukhin P. G. Determination of the carrying capacity of machines for the collection and removal of solid waste: Diss. ... Cand. Tech. Sci.: 05.05.04. - Moscow, 2004. – 196 p.

[12] Balovnev V.I. Evaluation of the efficiency of road and municipal vehicles according to technical and operational indices. - M.: MADI, 2002, 28 p.

[13] Balovnev V.I., Danilov R.G. Base vehicles and tractors for construction, road and utility vehicles. - M.: MADI, 2000, 69 p.

[14] Ermilov A.B. Calculation and design of special vehicles for the collection and removal of solid waste. -M.: MADI, 1983.99 p.

[15] Altunina M.S. Reliability studies of a garbage truck as a complex technical system / E.A. Shemshur, M.S. Altunina / Collection of scientific papers SWorld. Materials of the international scientific-practical conference "Perspective innovations in science, education, production, and transport 2014". - Issue 4 (37). Volume 2. - Odessa: KUPRIENKO, 2014. - P. 298-301.

[16] Teshome F.B. 2021 Municipal solid waste management in Ethiopia; the gaps and ways for improvement. (Journal of Material Cycles and Waste Management, volume 23), issue1, pp.18-31.

[17] Khankelov T.K. The choice of a utility machine with rational parameters according to the criterion of the minimum operating cycle time. Proceedings of the International Scientific and Technical Conference. Structural strength, seismodynamics of buildings and structures. Tashkent. 2016. P. 477-479.

[18] Khankelov T.K., Mukhamedova N.B., Komilov S.I., Mirkholikov S.M. System of Indices for Evaluating the Efficiency of Municipal Machines // International Journal of Advanced Research in Science, Engineering and Technology. 2022. Vol.9, Issue 11.- pp.20184-20187.

[19] Khankelov T.K., Mukhamedova N.B, Niyazov A.A. Description of the device for determining the mass of municipal solid waste. International journal of Novel Research in Advanced Sciences. Volume: 02, Issue 06/2023, ISSN 275-756X, pp.32-34.

[20] Khankelov T.K., Mukhamedova N.B, Rashidov B.U, Niyazov A.A. Selection of garbage trucks with rational parameters according to the criterion of minimum work cycle time. GALAXY INTERNATIONAL INTERDISCIPLINARY RESEARCH JOURNAL (GIIRJ). ISSN (E): 2347-6915. Volume 10, Issue 5, May 2022, pp.1087-1092.

[21] Marashlian N. 2005 Effect of food waste and wastewater management. (Waste Management Research). №23 (1), pp.20-31.

[22] Bolzonella D. 2003 The under-sink garbage grinder: a friendly technology for the environment. (Environmental Technology. Vol. 24), Issue 3, pp.349-359.

[23] Tursunov, Sh.S. 2021 Analysis of existing designs of crushers for crushing municipal solid waste. (International Journal for Innovative Engineering and Management Research. Vol 10), Issue 01, pp. 274-276.

[24] Khankelov T. Results of experimental studies of the process of sorting of elastic components of municipal solid waste// Academic journal of manufacturing engineering, 2021.Vol.19. Issue 07.-pp.97-102.

[25] Khankelov T.,Mukhitdinov A., Ibrokhimov S., Aslonov N., Mirkholikov S. Determination of the lengths of rebounds of elastic components of solid municipal waste // The 1st International Conference on problem and Perspectives of Modern Science AIP Conf.Proc.2022, pp.1-6.

[26] Road-building machines and complexes: A textbook for universities in the specialty "Road construction machines and equipment" / V.I. Balovnev et al.; Edited by V.I.Balovnev.-2nd ed., - Moscow. - Omsk: SibADI, 2001. - 528 p.