Choice of garbage trucks with rational parameters according to criterion of minimum operating cycle time

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Abstract. In conditions of limited commercial information on costs and rational costs, machines' efficiency and rational parameters at the stage of their manufacturing can be established based on an analysis of technical and operational indices. On this basis, the technical efficiency of the machine can be established. The corresponding technical and operational indices are calculated based on known technical parameters and operating conditions of the machine. These are such indices as specific energy consumption (kVt·h/m^3), material consumption (t·h/m^3), productivity (m^3/h), output per worker (m^3/w·h), and several generalized indices derived from the indicated ones. The choice of a rational solution is based on single-criteria optimization (on the one-criterion analysis).

1 Introduction

The collection and removal of municipal solid waste is an important sanitary operation carried out by municipal city services. Using garbage trucks with rational technical parameters, depending on the operating conditions, is one of the important reserves for reducing energy, material, and labor costs.

The choice of a garbage truck with rational technical and operational parameters for garbage collection in the shortest possible time includes several stages:

- establishing the features of the working cycle of the garbage truck as a cyclic machine;
- formation of a reasonable criterion of mathematical dependence in the form of an objective function, based on which the most rational machine can be chosen;
- development (based on the criterion) of a methodology for choosing a garbage truck with rational parameters for the corresponding operating conditions.

The garbage truck is a cyclically operating machine. Its purpose is the collection of municipal solid waste, loading the waste into a truck body and transporting it to the place of garbage reloading into a transport garbage truck. Then the work cycle is repeated. The collection and disposal of waste is an important sanitary and environmental operation that should be carried out as soon as possible. Garbage trucks generally have one engine, the power of which must be efficiently used for all operations of the working cycle.

When collecting garbage, the garbage truck moves at a minimum speed. To fully utilize the power and increase productivity, the garbage truck should be loaded as much as

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possible at this stage.

Transporting garbage is performed at the highest (permissible by traffic safety standards) speed. At a constant engine power, the increase in productivity in this operation is due to a decrease in the weight of the load.

These contradictions must be considered in the structure of the target criterion.

As a sanitary-ecological machine, a garbage truck must collect and take out household waste in the shortest possible time intervals. As an optimization criterion for this case, it is appropriate to use the operating efficiency of the garbage truck.

This index will allow us to choose a machine that will provide garbage removal at maximum performance in the shortest possible time. In this case, garbage collection and disposal is ensured per sanitary and economic requirements.

The studies of the processes of collection and transportation, as well as the processing of municipal solid waste, with the subsequent selection and justification of the main parameters of machines based on their operating conditions, are considered in publications of such scientists as V.I.Balovnev [1-3], G.L.Karaban [4], T.K.Khankelov [5-11], K.J.Rustamov [12-18].

2 Materials and methods

The performance of the garbage truck depends on the geometric capacity of the body V in m^3 and the cycle time duration in sec. Productivity is determined by the Prof. G.L. Karaban formula [4]:

$$P = \frac{3600 \cdot k_d \cdot k_u \cdot V}{t_{\sum c}}, m^3/h \qquad (1)$$

where V is the geometric capacity of the body, m^3; k_d is the body load factor; k_u is the garbage truck operation factor over time; $t_{\sum c}$ is the total time of the working cycle, sec.

The total cycle time is determined by the following formula

$$t_{\sum c} = t_d + t_{pf.d} + t_m + t_{mv} + t_{tr} + t_i + t_{pf.tr}, \text{ sec} \qquad (2)$$

where t_d is the average time of the main operation for loading the body, sec; $t_{pf.d}$ is time for preparatory of final operations to capture the container, sec; t_m is time for maneuvering when approaching the container, sec; t_{mv} is the average time for a garbage truck to move from container to container within a block, sec; t_{tr} is the average time to transport waste to the place of utilization, sec; t_i is the average time for the machine to return to its initial state, sec; $t_{pf.tr}$ is the time for preparatory and final operations during transportation, sec.

Formula (2) can be reduced to the following form (at $t_{tr} \approx t_i$)

$$P = \frac{3600 \cdot k_d \cdot k_u \cdot V}{k_{aux.d} \cdot t_d + k_{aux.tr} \cdot t_{tr}}, m^3/h \qquad (3)$$

where $k_{aux.d}$ is the coefficient that takes into account the duration of auxiliary operations during loading ($k_{aux.d}$, k_m, k_{mv}); $k_{aux.tr}$ is the coefficient that takes into account the duration of auxiliary operations ($k_{aux.tr}$) during unloading and transportation of the load. Other designations were given above.

Coefficients $k_{aux.d}$, $k_{aux.tr}$ are experimental values and determined by the following formula

$$k_{aux.d} = 1 + \frac{t_{pf.d} + t_m + t_{mv}}{t_d}$$

$$k_{aux.tr} = 1 + \frac{t_{pf.d}}{t_{tr} + t_i}$$

The designations accepted are given above.

Expressing in formula (3) the time for the loading operation (t_d), the transportation operation, and the return of a new portion of garbage (t_{tr}) by the technical and operational parameters of the garbage truck, we obtain

$$P = \frac{k_d \cdot V}{k_1 \frac{m_{kon}}{m} + k_2 \frac{f \cdot m \cdot l_{tr}}{N}}, m^3/h \tag{4}$$

where $k_1 = f(k_{aux.d}, h_d, V_d), sec$; $k_2 = \frac{k_{aux.d} \cdot k_c \cdot g}{\eta \cdot (1-\delta) \cdot k_{d.e}}, m/sec^2$; $k_d = 3600 k_d k_{f.c,} sec/h$; V is the geometric capacity of the body, m^3; m_{kon} is the mass capacity of garbage in a yard container, *kg*; m is the mass capacity of the body of the garbage truck, *kg*;f is coefficient of resistance to the movement of the garbage truck; l_{tr} is the distance of garbage transportation to the place of disposal or to the place of reloading into a transport garbage truck, *m*; *N* is the engine power of machine, *kVt*; h_d is the lifting height of the container when loading the body, *m*; ϑ_d is the lifting speed of the container, *m/sec*; k_c is coefficient that takes into account the movement of the garbage truck with load and the return without load; *g* is free-fall acceleration, $g = 9.81\ m/sec^2$; η is transmission efficiency; δ is the average coefficient of slipping; $k_{d.e}$ is the average engine load factor.

Other designations were given above.

Analysis (4) shows that productivity is maximal at the minimum value of the denominator – a 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; to use its power, it must be loaded as much as possible, i.e., the reduction in t_d is ensured by the increase in *m*.

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

The graph of the function (4) depending on the mass capacity of the body and the engine power of the base chassis *N* (for l_{tr}= 5 km, $k_{aux.d}$=60) is given in Fig.1.

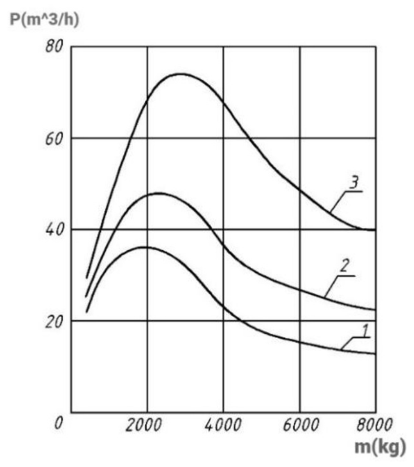

Fig. 1. Dependence of the operational performance of the garbage truck *P* on the mass performance of the body *m* and the engine power of the base chassis *N* for $l_{tr} = 5\ km$: $1 - N = 60\ kVt$; $2 - N = 90\ kVt$; $3 - N = 135\ kVt$

Figure 2 shows the dependence of function (4) on the mass capacity of the body m and the distance of garbage transportation l_{tr} (for $N = 135\ kVt, k_{aux.d} = 60$)

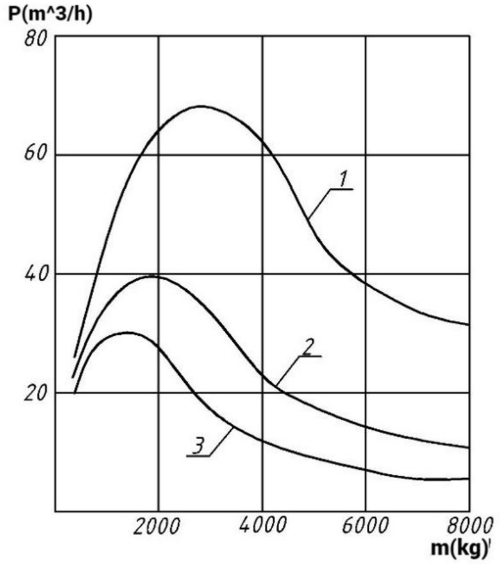

Fig. 2. Dependence of the operational performance of the garbage truck *P* on the mass productivity of the body *m* and the transportation distance l_{tr} for $N = 135\ kVt$: $1 - l_{tr} = 5\ km$; $2 - l_{tr} = 10\ km$; $3 - l_{tr} = 20\ km$

The optimal value of the mass is determined by equating the first derivative of the denominator in formula (4) to zero:

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

After differentiation, we have

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

From this expression, the optimal *m* is determined, at which the performance will have the maximum value.

$$k_1\frac{m_{\text{кон}}}{m^2} = k_2\frac{f \cdot l_{tr}}{N}, \text{ therefore, } m^2 = \frac{k_1 \cdot m_{\text{кон}} \cdot N}{k_2 \cdot f \cdot l_{tr}}, \quad \text{or}$$

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

We substitute k_1 and k_2

$$m_{opt} = \left(\frac{k_{aux.d} \cdot h_d \cdot \eta \cdot (1-\delta) \cdot k_{d.e} \cdot m_{\text{кон}} \cdot N}{V_d \cdot k_{aux.m} \cdot k_c \cdot g \cdot f \cdot l_{tr}}\right)^{1/2}, \text{к}g. \qquad (5)$$

Analysis of formula (5) shows that the optimal value m_{opt} of the mass capacity of the body depends on several factors.

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

Based on formula (5), dependencies $m_{opt} = f(l_{tr})$ and $N_{opt} = f(m_{opt})$ can be determined.

Formula (5) is transformed into the following form

$$m_{opt} = \frac{k \cdot N}{k_{кон} \cdot l_{tr}}, kg, \quad (6)$$

Where

$$k = \frac{k_{aux.d} \cdot h_3 \cdot \eta \cdot (1-\delta) \cdot k_{d.e}}{V_3 \cdot k_{aux.m} \cdot k_c \cdot g \cdot f}, sec^3/m \quad (7)$$

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

The graph of the dependence of the optimal value of the load capacity (5) m_{opt} on the transportation distance l_{tr} and the engine power of the base machine *N* is given in Fig. 3.

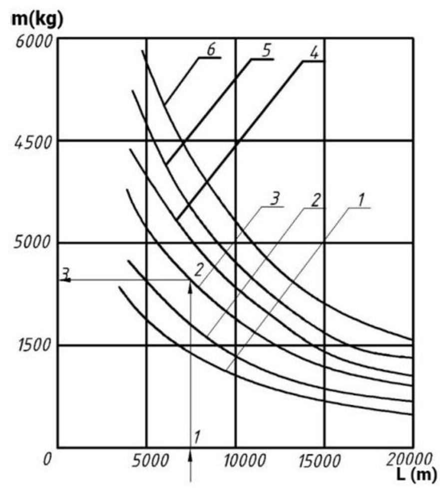

Fig. 3. Dependence of the optimal value of the mass capacity of the body m_{opt} on the distance of transportation of garbage l_{tr} and the engine power of the base machine *N*: $1 - N = 60\ kVt$; $2 - N = 75\ kVt$; $3 - N = 90\ kVt$; $4 - N = 115\ kVt$; $5 - N = 135\ kVt$; $6 - N = 150\ kVt$.

Based on (5), the rational value of power N_{rat} is determined depending on m_{opt}:

$$N = \frac{k_{кон}}{k} l_{tr} \cdot m_{opt}, \ kVt \quad (8)$$

The graph of the function (8) depending on the mass capacity of the body m_{opt} and the transportation distance l_{tr} is given in Fig.4.

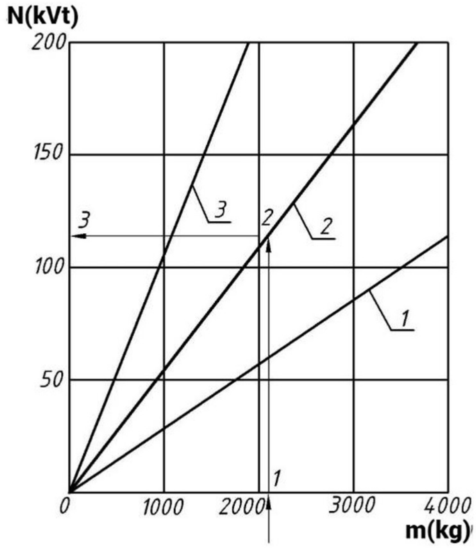

Fig. 4. Dependence of the rational power of the engine of the base machine N_{rat} and the optimal value of the mass capacity of the body m_{opt} on the distance of transportation of garbage l_{tr}: $1 - l_{tr} = 5\ km; 2 - l_{tr} = 10\ km; 3 - l_{tr} = 20\ km$

3 Results and discussion

The methodology for selecting garbage trucks with rational parameters for the operation according to the minimum operating cycle time criterion is based on minimizing the time for garbage collection and disposal operations or maximizing the performance of the garbage truck.

First, a truck is chosen that can travel on intra-block roads in a tight working area.

Then, according to the given average transportation distance l_{tr}, the optimal mass capacity of the 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}. The vertical line is drawn up to point 2, the intersection with the curve of the specified engine power. Then a horizontal line is drawn from point 2 until it intersects the vertical coordinate axis at point 3. This point gives the value of the optimal mass capacity of the body m_{opt}. Of the existing garbage trucks, the one is selected with the value of m the closest to m_{opt}.

The value of rational power is checked, as shown in the graph (Fig. 4). Point 1 is plotted on the horizontal axis by the value of m_{opt}, obtained on the graph in Fig. 3. The rational value of *N* is in point 3. A garbage truck with a capacity that best matches capacity N_{rat} is selected. The rational capacity can be determined by the calculation using the formula (8).

From the existing garbage trucks, the one chosen with parameters m and N that most closely correspond to the calculated parameters m_{opt} and N_{rat}, respectively.

4 Conclusion

1. A machine with rational parameters is determined based on the analysis of performance indices, considering operating conditions.
2. Optimization criteria, or performance indices, based on the analysis of rational

decisions, are chosen, considering the operator's goals.

3. The optimal parameters of the machine, set according to one of the efficiency criteria, may not coincide with other parameters set by other criteria.

4. In the enterprises of technical services and production of equipment, it is appropriate 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 operating conditions of equipment;

c) recommend to machine manufacturers the implementation of design modifications that increase the machine's operating efficiency.

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