Improving the process of transport of solid municipal waste by automobile transport

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Abstract. This article is devoted to the description of improvement of the transport process of solid municipal waste (SMW). The developed complex approach is presented, which allows one to improve the procedure of waste loading for preventing loading equipment failure, and also allowing increasing efficiency of the decision making process in case of emergency. The results of researching reliability of loading equipment are presented. The analysis of technical and economic indicators of specialized vehicle service using the developed complex approach is carried out.

1. Introduction
The problem of collecting and exporting of solid municipal waste (SMW) has been actual in Russia and abroad and still is. Ill-usage of waste among the population and lack of appropriate control lead to the fact that you can find not only municipal wastes in garbage bins but also more solid and heavy garbage, for example constructive. Density of SMW is changing in a wide range, that's why full garbage bins of the same volume can differ significantly by their weight. Garbage bins’ weight can be more than the maximum weight-carrying capacity of loading equipment in specialized vehicles for carrying and transporting SMW. However, the necessity of controlling the dynamic forces and different conditions of vehicle operation leads to the fact that enclosed equipment is adjusting for more pressure of power fluid (PF) and allows lifting garbage bins with more than maximum weight-carrying capacity. Lack of technical ability to define weight of SMW during bins lifting leads to increased wear of details. In many cases working capacity of loading equipment is disturbed and as a result motor vehicles stop working. Also there is a problem of organization on-time disposal of overloaded bins with the help of specialized vehicles, as there are no on-line data; it leads to breakdown of sanitary regulations in waste handling. Significant attention is paid to the questions of truck’s routes optimization in Russia and in other countries, especially garbage trucks and providing security while transporting dangerous wastes [1-7]. This shows how actual the topic of our research is.

The purpose of our research is to increase the capacity and operating reliability of specialized vehicles, which collect and transport SMW defining loaded weight and quick transportation management. A garbage truck works in two main regimes: transport regime (SHW disposal) and technological regime (collecting SHW). Working in the transport regime, the garbage truck moves between container yards and SHW disposal facility, and only a base unit is used in the working process. Loading and disposal back of a garbage truck with the help of special equipment is carried out in the
technological regime. Optimization and reduction of material cost on vehicle operation are the most important for increasing effectiveness of the vehicle company [8].

Having analyzed garbage trucks in Perm city, we found out that the most popular trucks are with side and back loading of SMW. According to data from testing areas, which have truck scales, the index of using weight-carrying capacity of trucks with the side loading is 0.52-0.63, and with the back loading is 0.66-1.47. Thus, some trucks with the back loading are overloaded in some routes.

Having analyzed methods of garbage weight determination, we decide that the most suitable way to define SMW weight is based on power fluid pressure measurement in the fluid power system of the vehicle’s loading equipment. This method can be implemented as a system, installed into the truck. The precision of measurements can be raised by taking into account an attitude of the loading equipment of specialized vehicle during the weighing process [9,10].

2. Methods

The mathematical model was developed for adjusting functional connections between characteristics changings of power fluid from weight value of upcoming load, while the specialized vehicle is working during the weighing process. Existing mathematical methods of calculating power liquid pressure changes depending on weight of upcoming load don’t take into consideration the attitude of the loaded equipment. That’s why we update the developed model of specialized vehicle operation. We have made an analysis of load change in the hydraulic-cylinder rod according to the attitude of the loading equipment of the specialized vehicle (Figure 1).

![Figure 1. Estimation scheme of the loading equipment:](image)

Using the principle of possible motion allows one to make a balance equation:

\[ p_1 \cdot S_{p1} \cdot \delta X_{g1} - m_b \cdot g \cdot \delta h = 0, \]

where 
- \( p_1 \) – pressure in the piston underside pot of the hydraulic cylinder lifting arm break, Pa;
- \( S_{p1} \) – piston area of the hydraulic cylinder lifting arm break, m²;
- \( \delta X_{g1} \) – possible motion of the hydraulic cylinder lifting arm break, m;
- \( m_b \) – weight of the garbage bin, H;
- \( g \) – activation of free falling, m/s²;
- \( \delta h \) – possible motion of the garbage bin, m.
We found pressure quantity in hydraulic cylinder $p_1$ from the balance equation by the method of transformation while weight lifting:

$$
p_1 = \frac{m_b \cdot g \cdot l_{DF} \cdot \sin(\phi_1) \cdot (l_1 + X_{g1})}{S_{p1} \cdot l_{BD} \cdot l_{CD} \cdot \sin(\phi_{02})},
$$

where $l_{DF}$, $l_{BD}$, $l_{CD}$ — geometric characteristics of loading equipment of specialized cars, m.

We use index $k$ for controlling the attitude of loading equipment; it is posed like current pressure ratio $p_1$ (2) to the maximum pressure $p_{1\text{max}}$ while lifting weight of the same mass, but with the different angle of handler tilt $\phi_1$:

$$k = \frac{p_1}{p_{1\text{max}}}.\]

Index $k$ is changing between 0 and 1; while weighing bins with SMW, it changes from 0.97 to 1.

While writing this article we have produced the prototype model for SMW weighing (figure 2). An indicator unit is used to inform the driver about emergency operation of loading equipment with the help of sound and warning lights.

![Figure 2. An exterior of the device.](image)

The terminal is used for collecting, processing and passing the data to the remote server. The terminal also has indicators which inform the driver about the current index of using weight-carrying capacity. An orange indicator is lighting up on the terminal and then - red when the weight loaded in the car body is close to nominal weight-carrying. This equipment was installed on specialized vehicles with side and back loading of the garbage (Figure 3).

![Figure 3. Installation of the equipment on specialized vehicles.](image)

### 3. Results

With the help of the device which defines weight we have made a calibration test to find the dependence between the pressure of power fluid in the hydro cylinder and weight loaded. The results are presented in figure 4.
The weighing process is made in a static position of the loading equipment after starting lifting the bin. Additionally, we explore the subject of appropriate continuance of the weighing process. We found out that the pressure in the hydro cylinder practically didn’t change in any pressure continuance. Lack of surge, sudden change of pressure allows one to define weigh loaded properly in the short period of time – 1-2 s.

![Figure 4. Dependence between loaded weight and power fluid pressure.](image)

According to the test data we have offered an integrative approach of organization and operative management of the transportation process of solid municipal waste on the basis of data about weight loaded. This approach involves developing methods of SMW loading in specialized vehicles with the possibility to define and control of the loaded weight and methods of operative management of the transportation process of the SMW on the basis of data about weigh loaded.

The procedure of SMW loading in specialized vehicles involves series of actions of the driver during the loading process and focused on SMW weight defining and preventing lifting of the overweight bins. According to the method, it is necessary to start bin lifting, before SMW loading after making training operations. If bin weight is so big that loading equipment can’t start to lift it, the red lamp on the indicator unit lights up and the driver can hear a warning signal, and he has to stop lifting process and start to load another bin. While doing this, one transmits information about emergency operating conditions of loading equipment to the remote server.

It is necessary to install loading equipment for weighing and then take device of weight determination off into a measurement mode with the help of the button on the indicator unit. The duration of static weighing is 1-2 sec. According to the results if the indicator unit lights up green then you should continue lifting, and if it is red then put the garbage bin down. Then using the button on the indicator unit, we take the device off into monitoring mode and continue loading SMW or lifting the next garbage bin.

The device collects, processes and transmits the data about date, time of SMW loading, positional data of loading, pressure and temperature data in power fluid, weight of SMW and current index of weight-carrying use of the vehicle.

Also the device can send the information about emergency conditions of the specialized vehicle.

We conduct an experiment according to the stated theory. The garbage bin with SMW was weighed with the help of the device and with the help of reliable warehouse scales with the full scale range from 0 to 500 kg. Relative measurement error was not more than 5%.

4. Discussion
The data from the devices about weight are used for management of the loading process. The method which allows one to increase management efficiency of the SMW transporting process (Figure 5) was developed according to the requirements of the standard.

This method allows supervisor to make decisions effectively in case of emergency conditions: in case of the overloaded garbage bin or possible excess of maximum permissible weight.
Real-life tests of the device show that 1-2% of the bins have weight which exceeds maximum permissible for loading equipment of the vehicle. Immediate disposition of garbage was made with the help of another vehicle.

Specialized vehicles with the side loading work take 50-60% from the maximum weight-carrying capacity, generally because of low index of garbage contraction. We examined two of six routes where specialized vehicles with the side loading were overloaded by 20-40%. Attempts of exceeding maximum permissible weight carried by specialized vehicles were prevented with the help of the device of controlling SMW weight. The index of using weight-carrying capacity of the vehicles was reduced up to 1.

![Diagram of efficient management of SMW transporting process]

**Figure 5.** Method of efficient management of the SMW transporting process.

Thus, introduction of the complex approach and device of weight defining allowed limiting loading of the vehicle, warning lifting of the overloaded bins and its disposal, decreasing the intensity of failures.
among loading equipment and increasing an average result in failure of hydraulic equipment from 5649 km or 20%, and metal construction from 14583 km up to 17143 km or 18%.

Having analyzed technical-economic factors of working of specialized vehicles using the complex approach and device for defining weight, we find out that introduction allows increasing annual profit from the vehicle working by 168 thousand rubles by means of increasing productivity by 5% and reducing annual costs per unit by 4%.

5. Conclusion
On the basis of the developed empirical-estimated connections and complex approach, we solved a very important applied-research task of increasing productivity and working reliability of specialized vehicles, which collect and transport SMW.

Evaluation of modern problems of vehicle operation shows that in some routes the index of using weight-carrying of specialized vehicles for collecting SMW is from 0.52 to 1.47. We find that on average 1-2% of bins are overloaded and lack of update information doesn’t allow one to organize well-timed disposal of such bins.

We worked out a mathematical model of specialized vehicle work, which allows one to calculate changes of power fluid pressure during weight lifting of different values. The model is supplied with index \( k \), which considers an attitude of the manipulator during weighing. It is established that during the weighing process index \( k \) varies from 0.97 to 1.

We worked out a complex approach to organization and quick management of carrying SMW on the basis of data about weight value. Using the complex approach allowed increasing reliability of loading equipment, limiting uploading of the vehicle and increasing the process of overloaded bins disposal.

Introduction of the device and the complex approach allowed one to increase annual profit from the specialized vehicles by 168 thousand rubles, by means of increasing productivity by 5% and reducing annual costs per unit by 4%.

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