



# Development of a Methodology for the Formation and Standardization of a Machine System for Road Construction and its Implementation

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## Abstract

This article presents the results of a study devoted to the development of a methodology for the formation and standardization of the labor intensity of a set of machines used in road construction. It is emphasized that the improvement of the efficiency of a road construction enterprise directly depends on the optimization of the use of the machinery fleet. A key factor of optimization is the development of a regulatory framework for the labor intensity of road construction machines, combined into complete and structured systems that take into account the specifics of technological processes in the construction of road elements. As a result of the conducted research, a methodology was developed for the formation and standardization of the labor intensity of a system of machines used in road construction. Within this methodology, block diagrams were developed, representing an algorithm for determining the need for road construction equipment to form an optimal system of machines intended for road construction, as well as an algorithm for its practical implementation. Additionally, nomograms were developed for the formation of a system of machines used in the construction of road elements, based on the developed normative values of the labor intensity of road construction equipment.

*Keywords:* Road construction; Machine system; Construction methodology; Road machinery.

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## 1. Introduction

In the implementation of a structural system within a production enterprise, special attention should be paid to identifying the development of priority sectors that will determine the prospects of our economy, the pace of scientific and technological progress, the development of communication systems, as well as road and railway networks, use technical resources effectively and ensure their timely renewal.

Modern road construction relies on a wide range of complex mechanization equipment. The most important task in ensuring technical equipment and improving the systems and structures of enterprises in this field is the comprehensive mechanization of highway construction work. Solving this task requires continuously expanding a road enterprise's fleet

of modern construction and road-building machines, increasing their productivity and operational reliability, optimizing their utilization, and ensuring proper maintenance.<sup>[1]</sup>

The development of industrial road construction methods is inextricably linked to the widespread use of sets of machines that ensure high productivity through automation and full mechanization of work, along with maximizing their usage.

Currently, with the emergence of new scientific fields, such as control theory, reliability theory, and technical diagnostics, and the widespread application of probability and queuing theory in engineering calculations, together with structured decision-making procedures, the theoretical foundations of machine operation are being significantly enriched.

The theory of machine operation aims to create and refine a normative and informational model that ensures the operational readiness of machine and equipment fleets, maximizing the reliability embedded at the design and production stages while accounting for specific operating conditions and minimizing costs.<sup>[2]</sup>

Special attention in operation is paid to the use of energy

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resources and, above all, fuel for the machine park. Road machinery operation is usually understood as a complex system of engineering, technical, and organizational measures to ensure the most efficient use of road machinery capabilities, high reliability, and safety, minimum downtime for maintenance and repair, as well as a high percentage of serviceability and readiness for work at minimum cost.<sup>[3]</sup>

Operation includes ensuring technically sound and economically efficient use of road machines, their maintenance and repair, as well as research aimed at improving the forms and methods of operating road machines during highway construction and maintenance.<sup>[4, 5]</sup>

## 2. Methods

Currently, improving the efficiency of the machine fleet of a road construction enterprise by forming a set of machines based on the developed normative labor intensity and productivity of road construction machinery for the construction of highway elements is an urgent task.

The developed “Norms” (hereinafter, Standards) serve as the main regulatory document for planning and providing the road construction industry with labor intensity benchmarks for modern machines and mechanisms, taking into account prospective volumes of work, thereby ensuring the completion of highway construction within specified deadlines while maintaining high quality and maximum economic efficiency.

The developed Standards substantiate the labor-intensity requirements for mechanized roadworks during the operation of modern road construction machines and mechanisms in highway construction.<sup>[6,7]</sup>

The developed Standards include a list of technological operations that specify the types of road works performed by modern road equipment and ensure high efficiency and quality. Additionally, they indicate the leading global firms and companies that manufacture these road construction machines, along with the approximate models and their key parameters.

The basis for the development and determination of normative labor intensity for construction and road machinery includes:

- the main types of roadwork in highway construction, established according to the approved classifier;
- technical and operational characteristics of road construction machines and mechanisms used in highway construction;
- results of an analysis of the range of modern, high-performance, and high-power road equipment by companies within and outside the CIS;
- unified, departmental, and standard norms for road construction and maintenance work carried out during highway construction;
- the results of calculations and operational time-study data for

the regulated types of roadwork in highway construction.<sup>[8, 9]</sup>

The calculation of the standard labor intensity of road construction machinery, taking into account the hourly operational productivity, is calculated using the following formula:

$$[t] = \frac{[V]}{P_h^o} \quad (1)$$

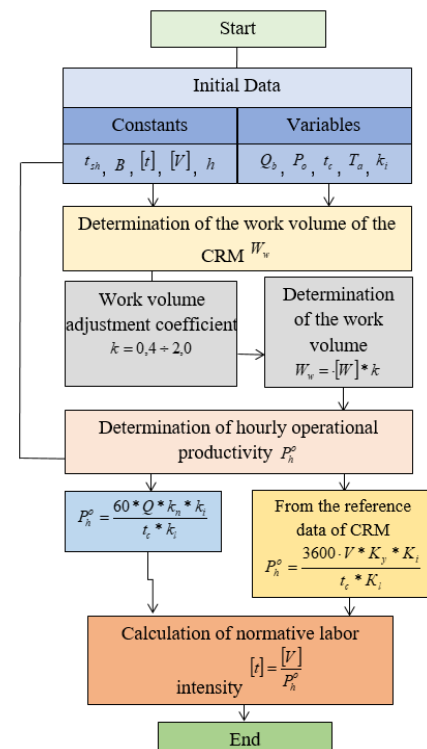
where  $P_h^o$  – hourly operational productivity of the road construction equipment;

$[V]$ – standard measurement of the volume of roadworks performed according to regulatory documentation (DCN, SCN, UPNR, etc.);

$[t]$ – standard time measurement for performing the normative volume of roadworks according to regulatory documentation (DCN, SCN, UPNR, etc.);

The hourly operational productivity of road construction works for a particular road equipment is determined by Eq. (1) presented in this methodology.

The block diagram of the algorithm for calculating the normative labor intensity of machines and mechanisms for roadworks in highway construction is presented in Fig. 1.



**Fig. 1:** Block diagram of the algorithm for calculating the normative labor intensity of machines and mechanisms in highway construction ( $t_{sh}$  – shift duration, h;  $B$  – road width according to the project, m;  $[t]$  – standard time for completing the normative work volume, h;  $[V]$  – standard work volume, m<sup>3</sup>;  $h$  – layer thickness according to the project, m;  $Q_b$  – bucket volume, m<sup>3</sup>;  $P_c$  – calculated productivity, m<sup>3</sup>/h;  $t_c$  – calculated time, h;  $t_a$  – annual operating time of machines, h;  $k_i$  – the coefficient of intra-shift time utilization,  $k_i = 0.70$  for loading into transport vehicles,  $k_i = 0.80$  working in spoil banks).

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The calculation of the hourly operational productivity of a single-bucket excavator is calculated using the following formula, m<sup>3</sup>/h:

$$P_o = \frac{3600 * q_b * k_y}{t_c * k_l} * k_{gr} * k_i * k_n \quad (2)$$

where  $q_b$  – bucket capacity of the excavator, m<sup>3</sup>;  $k_{gr}$  – the coefficient that takes into account the group of material and soil based on excavation difficulty (see Table 1);  $k_n$  – bucket fill factor,  $k_n = 0.9 \div 1.25$ ;  $t_c$  – the duration of one cycle of the excavator’s work, seconds;  $k_l$  – the soil loosening coefficient  $k_l = 1.1$  for loose materials and sandy soils, and  $k_l = 1.2$  for clayey soils;  $k_i$  – the coefficient of intra-shift time utilization,  $k_i = 0.70$  for loading into transport vehicles,  $k_i = 0.80$  working in spoil banks;  $k_T$  – the coefficient for transitioning from technical productivity to operational productivity,  $k_T = 0.60$ .

**Table 1:** Values of coefficient  $k_{gr}$ .

Group of material or soil	1	2	3	4
$k_{gr}$	1.0	0.8	0.65	0.5

The calculation of labor intensity standards for roadworks in highway construction using bulldozers takes into account the hourly operational productivity of the machines.<sup>[3,4,10]</sup> when developing and moving soil according to Eq. (3), when leveling materials and soils according to Eq. (4).

The hourly operational productivity of a bulldozer is calculated depending on the type of roadworks performed, using the following expressions, m<sup>3</sup>/h:

- for soil excavation and transportation:

$$P_h^o = 3600 * \frac{V_{pr}}{t_c * k_l} * k_{gr} * k_i * k_T \quad (3)$$

- for leveling materials and soils:

$$P_{b.l} = \frac{3600 * V_{pr}}{t_c * k_l} * k_{gr} * k_i * k_T \quad (4)$$

where  $V_{pr}$  – volume of the soil prism in front of the blade, m<sup>3</sup>;  $P_h^o$  – operational productivity of the bulldozer, m<sup>3</sup>/h;  $P_{b.l}$  – bulldozer productivity when leveling materials and soil, m<sup>3</sup>/h;  $t_c$  – full cycle time, sec;  $k_l$  – soil loosening coefficient;  $k_{gr}$  – coefficient that accounts for the material/soil group based on excavation difficulty (see Table 1);  $k_i$  – coefficient of intra-shift time utilization,  $k_i = 0.75$ ;  $k_T$  – coefficient for converting technical productivity to operational productivity,  $k_T = 0.70$ .

The labor-intensity standards for motor-grader operations productivity.<sup>[11]</sup> The Eq. (5) operational productivity of the motor grader is defined by the following formula, expressed in m<sup>3</sup>/h:

- in road surface profiling:

$$P_h^o = \frac{(b \cdot \sin \alpha - a) \cdot l_p}{\left(\frac{l_p}{1000 \cdot V_o} + t_{turn} + t_{shift}\right)} \cdot k_{gr} \cdot k_i \cdot k_T \quad (5)$$

- in the leveling of materials and soils:

$$P_h^o = \frac{V_o}{t_c \cdot k_{r.l}} \cdot k_{gr} \cdot k_i \cdot k_T \quad (6)$$

where  $b$  – blade length, m;  $\alpha$  – blade angle in plan view, averaged ( $\alpha = 50^\circ$ );  $a$  – track overlap width, m ( $a = 0.5$  m);  $l_p$  – pass length, assumed equal to the working section length, m;  $V_o$  – operating speed of the motor grader, km/h;  $k_{r.l}$  – coefficient considering the portion of dumped material or soil relocated during leveling,  $k_{r.l} = 0.75$ ;  $t_{turn}$  – motor grader turnaround time, h ( $t_{turn} = 0.01$  h);  $t_{shift}$  – time spent shifting gears, raising, and lowering the working unit, h ( $t_{shift} = 0.005$ h);  $n$  – number of passes over the same track ( $n = 3 \dots 4$ );  $k_{gr}$  – coefficient accounting for the material and soil group based on development difficulty (see Table 1);  $k_i$  – coefficient of intra-shift time utilization,  $k_i = 0.75$ ;  $k_T$  – coefficient for converting technical productivity to operational productivity,  $k_T = 0.70$ ;  $V$  – volume of soil in front of the blade, m<sup>3</sup>;  $t_c$  – full cycle time, h.

The determination of labor intensity norms for roadworks in highway construction employing a scraper is performed with consideration of the machine’s hourly operational productivity.

The operational Eq. (7) productivity of the scraper is calculated according to the following formula, m<sup>3</sup>/h:

$$P_h^o = \frac{60 * q_b}{t_c \cdot k_l} * k_i * k_T \quad (7)$$

where  $q_b$  – scraper bowl volume, m<sup>3</sup>;  $t_c$  – full cycle time, min;  $k_l$  – soil loosening coefficient ( $k_l = 1.1$  for sandy soils,  $k_l = 1.2$  for clayey soils);  $k_i$  – coefficient of intra-shift time utilization;  $k_T$  – coefficient for converting technical productivity to operational productivity,  $k_T = 0.60$ .

The determination of labor intensity standards for roadworks in highway construction employing compaction machinery is conducted with consideration of the equipment’s hourly operational productivity.<sup>[12, 13]</sup>

The hourly operational productivity of compaction machinery is calculated using the following formula, m<sup>3</sup>/h:

$$P_h^o = \frac{(b - a) \cdot l_p \cdot h_{c.l} \cdot k_{r.c}}{\left(\frac{l_p}{1000 \cdot V_o} + t_{tr}\right)} \cdot k_i \cdot k_T \quad (8)$$

where  $b$  – width of the compacted strip per pass, m;  $a$  – track overlap width, m ( $a = 0.2 \div 0.3$ m);  $l_p$  – pass length, m ( $l_p = 50 \dots 100$ m);  $h_{c.l}$  – thickness of the compacted layer in solid form, m;  $k_{r.c}$  – coefficient of reserve compaction depending on material type;  $k_i$  – coefficient of intra-shift time utilization,  $k_i = 0.75$ ;  $k_T$  – coefficient for converting technical productivity to operational productivity,  $k_T = 0.75$ ;  $\pi$  – number of passes per track;  $t_{tr}$  – time required to transition to the adjacent track, h ( $t_{tr} = 0.005$ h);  $V_o$  – operating speed, km/h.

The determination of labor intensity standards for roadworks in highway construction employing a single-bucket loader is performed with consideration of the equipment's hourly operational productivity.

The hourly operational productivity of a single-bucket loader is calculated using the following formula, m<sup>3</sup>/h:

$$P_h^o = \frac{q_l * k_i}{\rho * t_c} * k_T \quad (9)$$

where  $q_l$  – loader lifting capacity, t;  $t_c$  – full cycle time, h;  $\rho$  – bulk density of material or soil, t/m<sup>3</sup>;  $k_i$  – machine time utilization coefficient,  $k_i = 0.7 \div 0.8$ ;  $k_T$  – coefficient for converting technical productivity to operational productivity,  $k_T = 0.6$ .

A similar approach is used to calculate the labor intensity of other construction and road machinery involved in highway construction.

A group of machines operating in coordination and interconnected in terms of productivity and other principal parameters is referred to as a complex-mechanized machine set. Such a set typically includes one or more leading machines that perform the primary operation of the technological process and determine the pace and rhythm of work. The other machines, which operate in synchrony with the leading machine, are classified as auxiliary machines.

The functional specificity and diversity of engineering structures in highway construction necessitate the use of a broad range of construction and road machines and mechanisms, thereby enabling the formation of numerous diverse complex mechanized sets of machines.<sup>[14,15]</sup>

For the construction of the roadbed in highways, bulldozer, scraper, motor grader, and excavator–transport complexes of machines are commonly employed. In these complexes, the leading machines include bulldozers, scrapers, motor graders, and excavators, while the auxiliary machines comprise dump trucks, water-sprinkling equipment for moistening, and other specialized machinery.

When forming a set of machines and mechanisms, the requirements of the production process must be the primary consideration. Depending on the type and volume of work, the characteristics of the structure under construction, and the operating conditions of the equipment, the most appropriate types and models of machines should be selected, and their optimal number calculated to ensure the completion of the work volume within the prescribed timeframe.

At the same time, special attention must be paid to the mutual coordination of the main machine parameters, as smooth and uninterrupted operation of the entire set is impossible without it. Additional studies further support this conclusion.<sup>[16,17]</sup>

The main parameters of construction and road-building machines include performance, bucket capacity, load capacity, weight, working equipment width, etc.

In addition to leading and auxiliary machines, the machine sets also include backup machines, which are used in case of

failure of the leading or auxiliary (supporting) machines the Eq. (10) number.

Currently, the formation of equipment fleets commonly employs a deterministic approach. This approach assumes a conditional constancy in the operational productivity of the machines utilized over a defined time interval. Accordingly, Eq. (11) the number of leading machines required to complete the specified work volume within the established deadline is calculated using the following formula (units):

$$N_l = \frac{W_i}{P_{o.l} * n_{sh.m}} \quad (10)$$

where  $W_i$  – shift work volume in physical units;  $P_{o.l}$  – shift operational productivity of the leading machine in corresponding units;  $n_{sh.m}$  – regulated number of shifts for machine use:

$$T_w = \frac{W_i}{P_{o.l} * n' * N_l} \quad (11)$$

To determine the required number of machines of each type that form part of the auxiliary equipment, the following formula is applied Eq. (12)

$$N_a = \frac{P_{o.l} * N_l}{P_{o.a.m}} \quad (12)$$

where  $P_{o.a.m}$  – shift operational productivity of the auxiliary machine in the set.

At present, enhancing the efficiency of road construction enterprises through the rational formation of equipment sets for the construction of highway elements constitutes a pressing challenge.

This is particularly important under conditions of high traffic intensity, where road construction enterprises and their equipment fleets are supplied with diverse types of machinery from leading international manufacturers, as well as from producers within the CIS, in order to ensure high levels of technical safety in highway operations. In recent years, the Republic of Uzbekistan has witnessed a notable trend toward the introduction of modern, high-performance, powerful, and comfortable road construction machinery. The effective utilization of such equipment is achieved in the construction of highway elements through a comprehensive mechanized approach, *i.e.*, on the basis of a rationally formed set of Machines.

A machine set is a coordinated collection of main and auxiliary mechanization units interconnected by productivity and other key parameters. This set is required to carry out all technologically related processes and operations.

The primary (leading) machine in the set (bulldozer, excavator, asphalt paver, chippings spreader, etc.) must have sufficient productivity to complete the required volume of work within the specified deadlines at the given pace. The productivity of auxiliary machines in the set (bulldozers, rollers, water trucks, dump trucks, etc.) should be 10–15%

higher than that of the primary machine.<sup>[6,18]</sup>

The interaction of leading machines with auxiliary equipment within a set may be arranged according to sequential, parallel, or combined schemes. An example of a combined interaction scheme is presented in Fig. 2

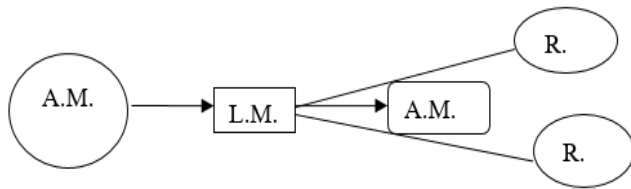


Fig. 2 Combined schematic diagram of machine interactions.

The developed block diagram of the algorithm for forming and calculating a rational set of machines for the construction of a highway element is shown in Fig. 3.

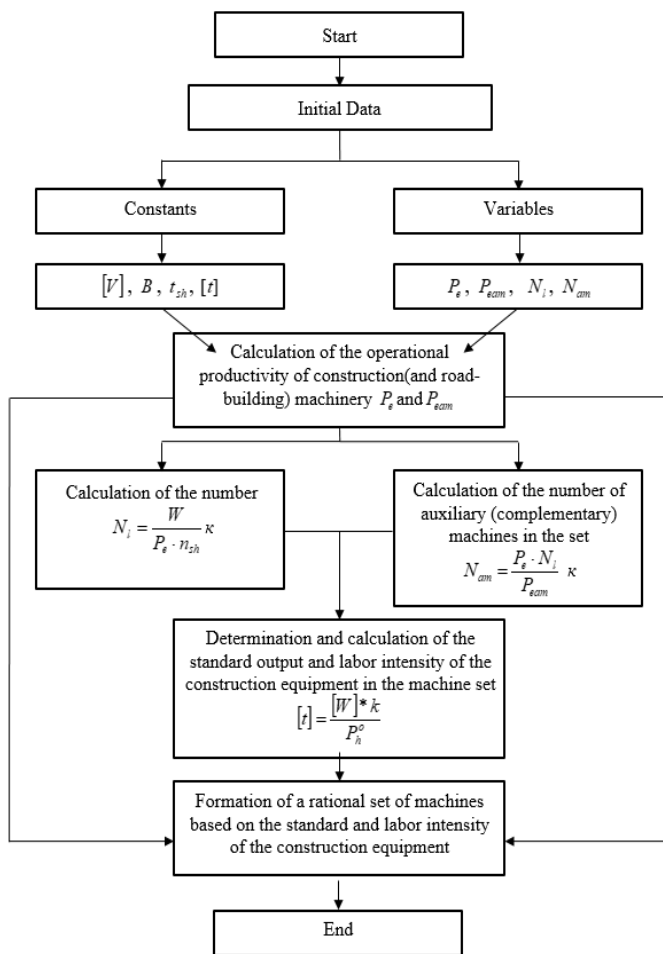


Fig. 3: Block diagram of the algorithm for forming a rational machine set for the construction of a highway element ( $t_{sh}$  – shift duration, h;  $B$  – road width according to the project, m;  $[t]$  – standard time for completing the normative work volume, h;  $[V]$  – standard work volume,  $m^3$ ;  $P_b$  – operational productivity,  $m^3/h$ ;  $P_{b.a.m}$  – estimated operational productivity of the auxiliary machine in the set;  $N_l$  – number of leading machines;  $N_{am}$  – number of auxiliary machines).

The system of machines for highway construction is

developed and structured on the basis of the technological processes involved in roadworks. This development takes into account modern advanced construction technologies as well as the deployment of high-performance and ergonomic road construction machinery.

Given the heterogeneity of machine fleets in terms of their principal technical characteristics, the formation of a rational machine set for the construction of highway elements necessitates the use of specialized approaches and methods aimed at coordinating and integrating diverse types of road construction machinery within the technological process. The objective is to ensure the seamless and uninterrupted operation of all machines included in the set. The system of machines for the construction of highway elements is presented in Table 2.<sup>[4]</sup>

### 3. Implementation of the methodology.

A comprehensive mechanized technology for working on the roadway of highways, depending on the composition of the machine set and on the type of the main leading machine, can be: bulldozer, motor grader, scraper, or excavator-transport.

In this work, we consider forming a rational set of machines with a bulldozer team, where the main leading machines for working on the roadway are bulldozers.

Bulldozer machine sets are most widely used for embankments up to 1.5–2 m in height and for the lower parts of higher embankments built from soil taken from side reserves or cuttings, with distances of soil movement up to 50–100 m. They can also be used on sloping sections where the soil is moved 10–30 m.

Bulldozers are produced on crawler tractors with engines rated from 96 to 220.8 kW, as well as on pneumatic wheel undercarriages with high traction effort. Modern bulldozers can have pivoting or fixed blades, with either hydraulic or cable control. Bulldozers with pivoting (universal) blades provide more intense cutting, which makes them better suited for dense soils and for cutting slopes and hillsides.

The bulldozer’s work cycle consists of the following operations: cutting into the soil, transporting it, depositing it, and then the empty return to the excavation (reserve). The time taken for these operations and the degree of tractor power utilization largely determine the bulldozer’s productivity.<sup>[19,20]</sup>

Soil excavation in reserves is carried out using a trench-strip method: trenches are formed perpendicular to the road’s axis, and each soil movement is done in crosswise strips. Trench excavation begins near the base of the embankment, moving soil toward its center.

Then, we carry out the calculation of a rational set of machines for constructing the roadbed. We begin the calculation by determining the normal labor intensity of the main leading machine – bulldozers.

The hourly operational productivity of the bulldozer is calculated using Eq. (3). As a first step, the volume of the soil prism pushed in front of the blade is calculated according

**Table 2:** Machine system for road embankment construction.

№	Construction of road elements	Type of roadwork	Recommended equipment and machinery	
			Machine name	Main machine parameter
1	Bulldozer Machine Set (Embankments up to 2.0 m high)	Embankment construction from side reserves	Bulldozer (main machine)	Power $\geq$ 118.0 kW
		Embankment leveling	Bulldozer	Power $\geq$ 96.0 kW
		Embankment grading	Medium-type motor grader	Power $\geq$ 99.0 kW
		Embankment compaction with rollers	Padfoot roller	Mass $\geq$ 12.0 t
			Combined roller	Mass $\geq$ 18.0 t
Embankment watering	Watering truck	Tank capacity $\geq$ 9 m <sup>3</sup>		
2	Scraper Machine Set (Embankments up to 6.0 m high)	Embankment construction by main machine	Scraper (main machine)	Bucket capacity $\geq$ 10.0 m <sup>3</sup>
		Embankment leveling	Bulldozer	Power $\geq$ 90.0 kW
		Embankment grading	Medium-type motor grader	Power $\geq$ 99.0 kW
		Embankment compaction with rollers	Padfoot roller	Mass $\geq$ 12.0 t
			Combined roller	Mass $\geq$ 18.0 t
			Pneumatic roller	Mass $\geq$ 24.0 t
Embankment watering	Watering truck	Tank capacity $\geq$ 9 m <sup>3</sup>		
3	Motor Grader Machine Set (Embankments up to 1.0 m high)	Embankment construction by main machine	Medium and heavy-type motor grader (main machine)	Power $\geq$ 99.0 kW
		Embankment leveling	Bulldozer	Power $\geq$ 90.0 kW
		Embankment grading	Medium-type motor grader	Power $\geq$ 99.0 kW
		Embankment compaction with rollers	Padfoot roller	Mass $\geq$ 12.0 t
			Combined roller	Mass $\geq$ 18.0 t
Pneumatic roller	Mass $\geq$ 24.0 t			
Embankment watering	Watering truck	Tank capacity $\geq$ 9 m <sup>3</sup>		
4	Excavator-Transport Machine Set (Embankments of any height)	Embankment construction with imported soil	Single-bucket excavator (main machine)	Bucket capacity $\geq$ 0.65 m <sup>3</sup>
			Dump truck	Load capacity $\geq$ 10.0 t
		Embankment leveling	Bulldozer	Power $\geq$ 90.0 kW
		Embankment watering	Watering truck	Tank capacity $\geq$ 9 m <sup>3</sup>

**Table 3:** Results of the experimental time study to determine the bulldozer’s cycle time.

№	Capture length, m	Cycle time		№	Capture length, m	Cycle time	
		In sec	In hours			In sec	In hours
1		42	0.0117	11		73	0.0120
2		36	0.010	12		39	0.010
3		33	0.0092	13		40	0.0112
4		39	0.0109	14		37	0.0103
5	30	35	0.0098	15	30	42	0.0117
6		40	0.0112	16		38	0.0106
7		38	0.0106	17		39	0.0109
8		37	0.0103	18		34	0.0095
9		34	0.0095	19		41	0.0114
10		41	0.0114	20		35	0.0098
Average						38	0.0106

to the following expression, expressed in m<sup>3</sup>:  
 The results of the experimental time study to determine the bulldozer’s cycle time (Table 3).

$$V_{pr} = \frac{0.75 * B * H^2}{k_l} * k_n \tag{13}$$

where B – blade width, m; H – blade height, m;  $k_n$  – coefficient accounting for soil losses during transportation,  $k_n=0.85$ ;  $k_l$  – soil loosening coefficient,  $k_l=1.2$  for clayey and topsoil.

By substituting the values into Eq. (13), the result is  $V_{pr} = 2.83 \text{ m}^3$ .

As part of this study on the operational process of the bulldozer, which serves as the leading machine in the set, an experimental time study was carried out to determine the duration of a single work cycle. The results of this experimental time study are summarized in Table 4. The average cycle time of the bulldozer is calculated as follows:

$$t_c = \frac{\sum t}{n} \tag{14}$$

Substituting the values into Eq. (14) yields  $t_c = 38$  seconds. The hourly productivity of the bulldozer is then calculated according to Eq. (3), m<sup>3</sup>/h:

$$P_h^o = 112.64 \text{ m}^3/\text{h}.$$

The normative labor intensity of the bulldozer is calculated using the following formula, expressed in machine hours:

$$[t] = \frac{[W]}{P_h^o} \tag{15}$$

Using Eq. (15), the normative labor intensity of the bulldozer is  $[t]=8,88$  machine-hours. Subsequently, the normative labor intensity of the motor grader during soil leveling is calculated according to Eq. (6),  $P_h^o = 76.85 \text{ m}^3/\text{h}$ .

$$P_h^o = \frac{76.85}{h_{c.l}} = \frac{76.85}{0.35} = 219.6 \text{ m}^2/\text{h}.$$

The normative labor intensity of the motor grader is then calculated using Eq. (15),  $[t] = 4.55$  machine hours.

To calculate the standard labor intensity of a bulldozer during embankment construction by soil leveling, the volume of the soil prism pushed in front of the blade is determined using the following expression:

$$V_{pr}=3.05\text{m}^3$$

The hourly operational productivity of the bulldozer is calculated according to Eq. (3):

$$P_h^o = 144.1\text{m}^3/\text{h}.$$

Then the standard labor intensity of the bulldozer is

$$[t] = 6.94 \text{ machine-hours}.$$

The calculation of the standard labor intensity of the sheepsfoot combination roller with a mass of 15 tons is calculated using Eq. (8):

$$P_h^o = 146.3 \text{ m}^3/\text{h}.$$

Then the standard labor intensity of the padfoot roller is

$$[t] = 6.84 \text{ machine-hours}.$$

The calculation of the standard labor intensity of a combined roller with a mass of 19.6 tons is calculated using Eq. (8):

$$P_h^o = 132.5 \text{ m}^3/\text{h}.$$

Then, the standard labor intensity of the combined roller is equal to

$$[t] = 7.54 \text{ machine-hours}.$$

The results of the experimental time-study of the combined roller to determine the average operating speed are presented in Table 4.

The analysis of the results from the experimental time study in Table 4 for determining the average operating speed of the combined roller shows that

**Table 4:** Results of the experimental time study of the combined roller's operation.

№	Pass length, m	Pass time, sec	Operating speed, m/s	Operating speed, km/h	Average operating speed, km/h
1		14	1.429	5.14	
2		11	1.818	6.55	
3		13	1.539	5.54	
4	20	12	1.667	6.00	5.78
5		15	1.333	4.80	
6		11	1.818	6.55	
7		14	1.429	5.14	
8		10	2.00	7.20	
9		15	1.333	4.80	
10		12	1.667	6.00	
11		14	1.429	5.14	
12		11	1.818	6.55	

$$V_{avg} = \frac{\sum V_p}{n} = 5.78.$$

The calculation of the standard labor intensity for the pneumatic roller with a weight of 26.0 tons is calculated using Eq. (8):

$$P_h^o = 126.88 \text{ m}^3/\text{h}.$$

Then, the standard labor intensity of the pneumatic roller is

$$[t] = 7.88 \text{ machine-hours}.$$

The standard labor intensity for watering machines with a tank capacity of  $q = 9.0\text{m}^3$  is calculated using the formula,  $\text{m}^2/\text{h}$ :

$$P_h^o = \frac{1000 \cdot (b-a) \cdot V_o \cdot t_d}{\frac{2L}{V} + t_f + t_d} \cdot k_i \cdot k_T \quad (16)$$

where  $b$  - width of the treated strip,  $\text{m}$ ;  $a$  - width of the overlap of the treated strip in cases where the entire strip to be treated is larger  $b$  ( $a = 0.10 \text{ m}$ );  $V_o$  - operating speed,  $\text{km/h}$ ;  $L$  - transportation distance of water,  $\text{km}$ ;  $V$  - water transportation speed,  $\text{km/h}$ ;  $t_f$  - time for filling the tank ( $t_f = 0.15\text{h}$  at  $q \leq 6.0\text{m}^3$ );  $t_d$  - time required for emptying the tank during water distribution is calculated using the following formula, hours.

$$t_d = \frac{q_t}{\rho \cdot (b-a) \cdot V_o} \quad (17)$$

$q_t$  - tank capacity,  $\text{m}^3$ ;  $\rho$  - dispensing norm,  $\text{m}^2/\text{m}^3$ ;  $k_i$  - coefficient of intra-shift time utilization,  $k_i = 0.75$ ;  $k_T$  - coefficient of transition from technical performance to operational performance,  $k_T = 0.70$ .

Using Eq. (17), the time required for emptying the tank is

$$\text{calculated: } t_d = 0.0038\text{h}.$$

Using Eq. (16), the productivity of the watering machine is calculated:

$$P_h^o = 577.9\text{m}^2/\text{h}.$$

Taking into account the thickness of the subgrade layer, the productivity of the watering machines is

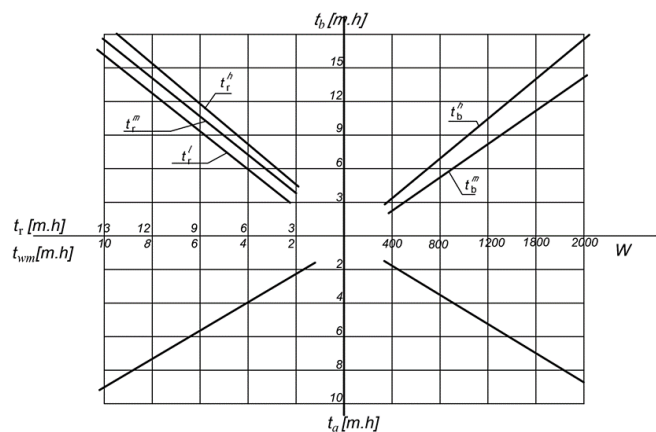
$$P_h^o = P_h^{\prime o} \cdot h_{c.l} = 202.27\text{m}^3/\text{h}.$$

Then, the standard labor intensity of the watering machines is defined as

$$[t] = 4.94 \text{ machine-hours}.$$

#### 4. Results

The developed nomogram for determining the labor intensity of the machinery set for subgrade construction is presented in Fig. 4.



**Fig. 4:** Nomogram for determining the labor intensity  $t_i$  of the machinery set for earthworks construction.

The developed nomogram for determining the labor intensity  $t_i$  of a rational machine set for earthwork construction enables one to establish the labor intensity values of the road-building equipment included in the machine set for embankment formation. It is known that a machine set consists of a leading (primary) machine and component auxiliary machines, as shown in Fig. 4. For a given standard volume of work, the nomogram makes it possible to determine the labor intensity of each road-construction machine in the bulldozer machine set, namely: bulldozers  $t_b$ , motor graders  $t_a$ , and compaction machines (light  $t_r^h$ , medium  $t_r^m$ , heavy  $t_r^l$ ) and etc.

The results of the calculations for the optimal machinery set for earthworks construction are presented in Table 5.

The technological process of constructing foundations from crushed stone and gravel-stone materials involves a set of machines for performing this roadwork, which are formed based on the machines and their components.

It is known that the main leading machine in the set in this case can be a gravel distributor or a loading-transport machine, on the basis of which the optimal set of machines is formed, consisting of auxiliary components as well as backup machines.

The calculation of the standard labor intensities for the optimal set of machines for the construction of road foundations from crushed stone and gravel-sand mixture is carried out according to the developed methodology, taking into account the main key parameters of road construction

machinery.

1. The productivity of the primary leading machine, the stone spreader, is calculated using the following formula, expressed in  $m^2/h$ :

$$P_h^o = V_o(B - a) * k_{r.c} * k_i * k_T \tag{18}$$

where  $V_o$  - operating speed of the machines, m/h;  $B$  - width of the foundation layer being laid, m;  $a$  - width of the overlap of adjacent strips in the case of laying the layer in several strips, m;  $a = 0.1 \div 0.15m$ ;  $k_{r.c}$  - coefficient of reserve compaction depending on material type;  $k_i$  - coefficient of intra-shift time utilization,  $k_i = 0.75$ ;  $k_T$  - coefficient of transition from technical to operational performance,  $k_T = 0.75$ .

By substituting the values into Eq. (18), the productivity of the primary leading machine, the stone spreader, is calculated:

$$P_h^o = 685.55m^2/h$$

The standard labor intensity of the main leading machine, the gravel distributor, is defined as:

$$[t] = 1.46 \text{ machine-hours.}$$

2. The results of the time study of the working process of a single-bucket loader, determining the duration of one work cycle during  $t_c$  loading of road transport, are presented in Table 6.

The results of the time study of the working process of the

**Table 5:** Standard labor intensities of the optimal machinery set for earthworks construction.

№	Machine name	Main parameter	Normative measurements, m <sup>2</sup>								
			400	600	800	1000	1200	1400	1600	1800	2000
1	Bulldozer	120 kW	3.55	5.38	7.10	8.88	10.66	12.43	14.21	15.98	17.76
2	Medium-type motor grader	99 kW	1.82	2.73	3.64	4.55	5.46	6.37	7.28	8.19	9.10
3	Bulldozer	103 kW	2.78	4.16	5.55	6.94	8.33	9.72	11.10	12.49	13.88
4	Combined padfoot roller	15.0 kW	2.74	4.10	5.47	6.84	8.21	9.58	10.94	12.31	13.68
5	Motor grader with a wing	99 kW	1.26	1.89	2.53	3.16	3.79	4.42	5.06	5.69	6.32
6	Combined roller	19.6 t	3.02	4.52	6.03	7.54	9.05	10.56	12.06	13.57	15.08
7	Pneumatic-tired roller	26.0 t	3.15	4.73	6.30	7.88	9.46	11.03	12.61	14.18	15.76
8	Watering machine	9.0 m <sup>3</sup>	1.98	2.96	3.95	4.94	5.93	6.92	7.90	8.89	9.88

**Table 6:** Results of the time study of the working process of a single-bucket loader during the loading of crushed stone into road transport.

№ measurement	of Loading time		№ measurement	of Loading time	
	sec	hour		sec	hour
1	59	0.0164	18	60	0.0167
2	55	0.0153	19	54	0.0150
3	63	0.0175	20	63	0.0175
4	56	0.0156	21	56	0.0156
5	61	0.0170	22	62	0.0172
6	59	0.0164	23	51	0.0142
7	54	0.0150	24	58	0.0162
8	58	0.0162	25	52	0.0145
9	56	0.0156	26	56	0.0156
10	53	0.0148	27	59	0.0164
11	57	0.0159	28	55	0.0153
12	55	0.0153	29	58	0.0162
13	62	0.0172	30	60	0.0100
14	56	0.0156	31	56	0.0156
15	63	0.0175	32	51	0.0142
16	54	0.0150			
17	52	0.0145			
Average				57	0.0159

**Table 7:** Results of the time study for determining the average speed of the light roller BOMAG BW 145.

№	Grip length $l_e$ , m	Duration of passage $t$ , sec	Operating speed		Average operating speed
			$V_p$ , m/s	$V_p$ , km/h	$V_p^{cp}$ , km/h
1	50	42	1.191	4.288	4.208
2		39	1.282	4.615	
3		43	1.163	4.187	
4		46	1.087	3.913	
5		45	1.111	3.999	
6		44	1.136	4.090	
7		41	1.219	4.388	
8		43	1.282	4.187	

single-bucket loader from Table 7 show that the duration of one work cycle  $t_c$  is:

$$t_c = 57 \text{ sec or } t_c = 0.0159 \text{ h.}$$

Calculation of the standard labor intensity for the single-bucket loader.

The hourly productivity of the single-bucket loader is calculated using Eq. (9):

$$P_h^o = 83.33 \text{ m}^3/\text{h.}$$

Taking into account the thickness of the layer, the productivity of the machines is defined as:

$$P_h^o = 555.55 \text{ m}^2/\text{h.}$$

Then, the standard labor intensity of the single-bucket loader is:

$$[t] = 1.80 \text{ machine-hours.}$$

The calculation of the hourly operational productivity of the dump truck is calculated using the following formula:

$$P_h^o = \frac{q_{dt} * k_i * k_T}{\rho \left( \frac{2L}{V} + t_l + t_u \right)} = 11.92 \text{ m}^3/\text{h.}$$

The normative labor intensity of the dump truck is:

$$[t] = \frac{[V] \cdot hc.l}{P_h^o} = 8.86 \text{ mach.hr}$$

where  $h_{c,l}$  the thickness of the crushed stone base layer,  $h_{c,l} = 15 \text{ cm or } h_{c,l} = 0.15 \text{ m.}$

4. Next, we proceed with the determination and calculation of the standard labor intensities of the compaction machines

included in the optimal machinery set.

The results of the time study of the working process for determining the average operating speed of light-type compaction machines are presented in Table 7.

We determine the standard labor intensity  $[t]$  of light-type compaction machines based on their hourly productivity  $P_h^o$ , which is calculated using Eq. (8):

$$P_h^o = 483.88 \text{ m}^2/\text{h}.$$

The standard labor intensity  $[t]$  of the light-type compaction roller is defined as:

$$[t] = 2.07 \text{ machine-hours}.$$

5. Next, we determine the standard labor intensity  $[t]$  of the medium-type roller. The results of the time study for determining the average speed of the roller are presented in Table 8.

The hourly operational productivity of the medium-type roller is calculated using Eq. (8):

Then, the standard labor intensity of the heavy-type roller is defined as:

$$[t] = 4.94 \text{ machine-hours}.$$

6. The calculation of the standard labor intensity  $[t]$  of the heavy-type roller has been carried out. The results of the time study for determining the average speed of the roller are presented in Table 9.

The calculation of the hourly productivity is calculated using Eq. (8):

$$P_h^o = 176.8 \text{ m}^2/\text{h}.$$

Then, the standard labor intensity of the heavy-type roller is defined as:

$$[t] = 5.66 \text{ machine-hours}.$$

The calculation of the standard labor intensity  $[t]$  of the watering machine included in the optimal machinery set.

**Table 8:** Results of the time study for determining the average speed of the medium roller model HAMM HD 110 K.

№	Grip length $l_e$ , m	Duration of passage $t$ , sec	Operating speed		Average operating speed
			$V_o$ , m/s	$V_o$ , km/h	$V_o^{avg}$ , km/h
1	50	35	1.429	5.144	5.473
2		32	1.563	5.625	
3		30	1.667	6.001	
4		31	1.613	5.806	
5		34	1.471	5.296	
6		33	1.515	5.455	
7		31	1.613	5.806	
8		35	1.429	5.144	
9		32	1.563	5.625	
10		34	1.471	5.296	
		36	1.389	5.001	

**Table 9:** Results of the time study for determining the average speed of the heavy roller model HAMM GRW 18.

№	Grip length $l_e$ , m	Duration of passage $t$ , sec	Operating speed		Average operating speed
			$V_o$ , m/s	$V_o$ , km/h	$V_o^{avg}$ , km/h
1	50	29	1.724	6.207	6.507
2		26	1.923	6.923	
3		28	1.786	6.429	
4		30	1.667	6.007	
5		27	1.852	6.667	
6		29	1.724	6.807	
7		26	1.923	6.923	
8		28	1.786	6.429	
9		27	1.852	6.607	
10		26	1.923	6.923	
11		29	1.724	6.207	

Results. The developed nomogram for determining the labor intensity of the machinery set for the construction of a crushed stone base is presented in Fig. 5.

The developed nomogram determines the labor intensity of a rational machine set for the construction of a crushed-stone base and pavement, allowing one to establish the labor intensity values of each machine and mechanism included in the set. Given a normatively established volume of roadworks  $[W]$ , the nomogram enables the determination of the labor intensity of each unit of road-building equipment, namely: gravel spreader ( $t_{gs}$ ), single-bucket loader ( $t_{sb}$ ), compaction machines ( $t_r$ ) subdivided by type (light  $t_r^h$ , medium  $t_r^m$ , heavy  $t_r^l$ ), watering-and-washing vehicles, as well as automobile transportation ( $t_{dt}$ ).

The developed standard labor intensities for the optimal machinery set for the construction of a crushed stone base are presented in Table 10.

Furthermore, within the framework of this study, the working processes of road construction machinery included in the rational machine set for constructing a gravel base were

examined. The normative labor intensity of road construction machinery for gravel base construction was determined using the same methodology as applied to crushed stone base construction. Using the same methodology as for the crushed-stone base, the obtained results of the normative labor intensity  $[t]$  for the rational machine set applied to gravel base construction are presented in Table 11. Determination of the operational productivity of a single-bucket excavator when loading gravel onto vehicles is determined by Eq. (2).

The developed nomogram for determining the labor intensity of the machine set for gravel base construction is presented in Fig. 6.

Rational set of machines for asphalt concrete pavement is formed on the basis of road construction machines according to the technological process of roadworks. As the structure and composition of the set of machines is adopted, the leading, auxiliary and reserve machines are included. For the construction of asphalt concrete pavement, the main leading machine is an asphalt paver for laying asphalt concrete mixture, which sets the pace and rhythm of work.

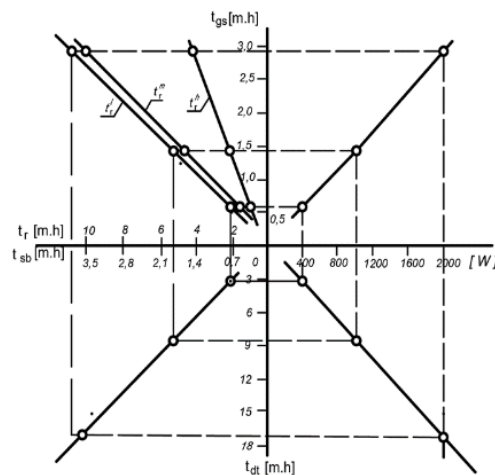


Fig. 5: Nomogram for determining the labor intensity  $t_i$  of the machinery set for the construction of a crushed stone base.

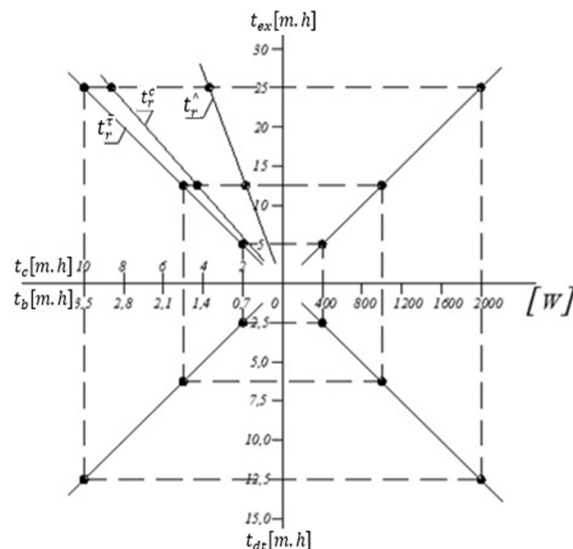


Fig. 6: Nomogram for determining the labor intensity  $t_i$  of the machine set for gravel base construction.

**Table 10:** Standard labor intensities of the rational set of machines for crushed stone foundation construction.

№	Machine name	Main parameter	Normative measurements, m <sup>2</sup>									
			400	600	800	1000	1200	1400	1600	1800	2000	
1	Gravel spreader	Laying width 3.0 ÷ 7.0 m	0.58	0.88	1.17	1.46	1.75	2.04	2.34	2.63	2.92	
2	Single-bucket loader	Load capacity not more than 5.0 t	0.72	1.08	1.44	1.80	2.16	2.52	2.88	3.24	3.60	
3	Light-type roller	Weight up to 6.0 t	0.83	1.24	1.66	2.07	2.48	2.89	3.31	3.73	4.14	
4	Medium-type roller	Weight 7.0 ÷ 12.0	1.98	2.96	3.95	4.94	5.92	6.92	7.90	8.89	9.88	
5	Heavy roller	Weight more than 13.0 -18 t	2.26	3.40	4.53	5.66	6.79	7.92	9.06	10.19	11.32	
6	Dump truck	Load capacity of 16.0 t or more	3.54	5.32	7.09	8.86	10.63	12.40	14.18	15.95	17.72	
7	Watering machine	Tank capacity of 6.0 m <sup>3</sup> or more	0.34	0.52	0.69	0.86	1.03	1.20	1.38	1.55	1.72	

**Table 11:** Normative labor intensities of a set of machines for construction of gravel base.

№	Machine name	Main machine parameter	Normative measurements, m <sup>2</sup>									
			400	600	800	1000	1200	1400	1600	1800	2000	
1	Single-bucket Excavator	Bucket capacity 0.65 m <sup>3</sup> and more	5.29	7.94	10.58	13.23	15.88	18.52	21.17	23.81	26.46	
2	Bulldozer	Power 118 kW	0.70	1.07	1.41	1.76	2.11	2.46	2.82	3.17	3.52	
3	Medium-type Motor Grader	Power over 100 kW	0.43	0.65	0.86	1.08	1.30	1.51	1.73	1.94	2.16	
4	Light-type Roller	Weight up to 7.0 t	0.75	1.13	1.50	1.88	2.26	2.63	3.01	3.38	3.76	
5	Medium-type Roller	Weight 8-12.0 t	1.87	2.81	3.74	4.68	5.62	6.55	7.49	8.42	9.36	
6	Heavy-type Roller	Weight over 13 t	2.05	3.07	4.10	5.12	6.14	7.17	8.19	9.22	10.24	
7	Watering and Washing Machine	Tank volume over 6000 l	0.47	0.71	0.94	1.18	1.42	1.65	1.89	2.12	2.36	
8	Dump Truck	Payload capacity over 16 t	2.77	4.15	5.54	6.92	8.30	9.69	11.07	12.46	13.84	

The auxiliary machines in the set include the bitumen distributor; compaction machines (light, medium, and heavy-type rollers); and the dump truck.

Formation of a rational set of machines for the construction of asphalt concrete pavement production on the basis of normative labor intensity of road equipment included in the set of machines. Calculation is made on the normative measure of the volume of work for a rational set of machines for the construction of asphalt concrete pavement, which is taken as 1000 m<sup>2</sup>.

1. Calculation of normative labor intensity for the machine included in the asphalt paver set is made in the following sequence: first, the hourly operational productivity is calculated, and then the labor intensity of the asphalt paver is determined.

The calculation of the hourly operational productivity of the asphalt paver is calculated using the following formula, m<sup>2</sup>/h:

$$P_h^o = V_o(B - a) * k_{r.c} * k_i * k_T, \tag{19}$$

where  $V_o$  - operating speed of the asphalt paver, m/h;  $B$  - width of the asphalt concrete mix laying, m;  $k_i$  - the coefficient of inter-shift time utilization,  $k_i = 0.75$ ;  $a$  - width of overlap of adjacent lanes when laying the layer in multiple lanes, m ( $a = 0.05$ m);  $k_{r.c}$  - the coefficient of reserve for compaction  $k_{r.c} = 1.25 ÷ 1.30$ ; taking  $k_{r.c} = 1.28$ ;  $k_T$  - the coefficient for the transition from technical productivity to operational productivity,  $k_T = 0.75$ .

By substituting the values into Eq. (19), we obtain the hourly operational productivity of the asphalt paver:  $P_h^o = 710.95$  m<sup>2</sup>/h. The Eq. (20) calculation of the normative labor intensity of the asphalt paver is calculated using the following formula, machine-hours:

$$[t] = \frac{[V]}{P_h^o} \tag{20}$$

where  $[V]$ - is the normative work volume measurer,  $[V] = 1000$  m<sup>2</sup>;  $[t]$ - is the normative labor intensity of the asphalt

paver for performing the work volume [V], machine-hours.

$$[t] = 1.41 \text{ machine-hours}$$

2. The normative labor intensity of the MAN TG 280 dump truck with a 20-ton carrying capacity, intended for transporting asphalt concrete mixture, was calculated.

The Eq. (21) hourly operational productivity of the dump truck is determined using the formula, m<sup>3</sup>/h:

$$P_h^o = \frac{q_{dt} * k_i * k_T}{\rho \left( \frac{2L}{V} + t_l + t_u \right)} \quad (21)$$

where  $q_{dt}$  - payload capacity of the dump truck, t;  $k_i$  - coefficient of inter-shift time utilization,  $k_i = 0.75$ ;  $k_T$  - coefficient for the transition from technical productivity to operational productivity,  $k_T = 0.70$ ;  $L$  - transportation distance, km;  $t_l$  - loading time of the dump truck, h;  $t_u$  - unloading time of the dump truck, h;  $V$  - speed of movement, km/h.

The operational productivity of the dump truck is defined as:

$$P_h^o = 12.83, \text{ m}^3/\text{h}.$$

Then, the normative labor intensity of the dump truck is:

$$[t] = \frac{[V]*h}{P_h^o} = \frac{1000*0.06}{12.83} = 4.68 \text{ machine-hours}.$$

3. We determine the normative labor intensity of light, medium and heavy-type compaction machines. The results of the chronometric measurement of the average speed of compaction machines of different types are presented in Table 12.

The calculation of the normative labor intensity for light-type compaction machines weighing up to 6.0 t.

The calculation of the hourly operational productivity of a light-type roller is calculated using Eq. (8):

$$P_h^o = 592.1 \text{ m}^2/\text{h}.$$

Then, the normative labor intensity [t] of light-type compaction machines is defined as:

$$[t] = 1.69 \text{ machine-hours}.$$

The results of the chronometric measurement of the average speed of medium-type compaction machines are presented in Table 13.

The hourly operational productivity of the medium-type roller is calculated using Eq. (8):

$$P_h^o = 433.13 \text{ m}^2/\text{h}.$$

Then, the normative labor intensity [t] of the medium-type roller is defined as:

**Table 12:** Results of the chronometric measurement of the average operating speed of the light-type roller, model HAMM HD 15 V.

№	Grip length $l_e, \text{ m}$	Duration of passage $t, \text{ sec}$	Operating speed		Average operating speed
			$V_o, \text{ m/s}$	$V_o, \text{ km/h}$	$V_o^{avg}, \text{ km/h}$
1	50	53	0.94	3.38	3.509
2		49	1.02	3.67	
3		52	0.96	3.46	
4		54	0.93	3.35	
5		51	0.98	3.53	
6		50	1.00	3.60	
7		53	0.94	3.38	
8		48	1.04	3.75	
9		52	0.96	3.46	

**Table 13:** Results of the chronometric measurement of the average operating speed of the medium-type roller, model BOMAG BW 141.

№	Grip length $l_e, \text{ m}$	Duration of passage $t, \text{ sec}$	Operating speed		Average operating speed
			$V_o, \text{ m/s}$	$V_o, \text{ km/h}$	$V_o^{avg}, \text{ km/h}$
1	41	43	1.16	4.18	4.61
2		38	1.31	4.72	
3		41	1.22	4.39	
4		39	1.28	4.61	

№	Grip length $l_e, m$	Duration of passage $t, sec$	Operating speed		Average operating speed
			$V_o, m/s$	$V_o, km/h$	$V_o^{avg}, km/h$
5		40	1.25	4.50	
6	50	37	1.35	4.86	4.504
7		42	1.19	4.28	
8		39	1.28	4.61	
9		38	1.31	4.72	
10		42	1.19	4.28	
11		41	1.22	4.39	

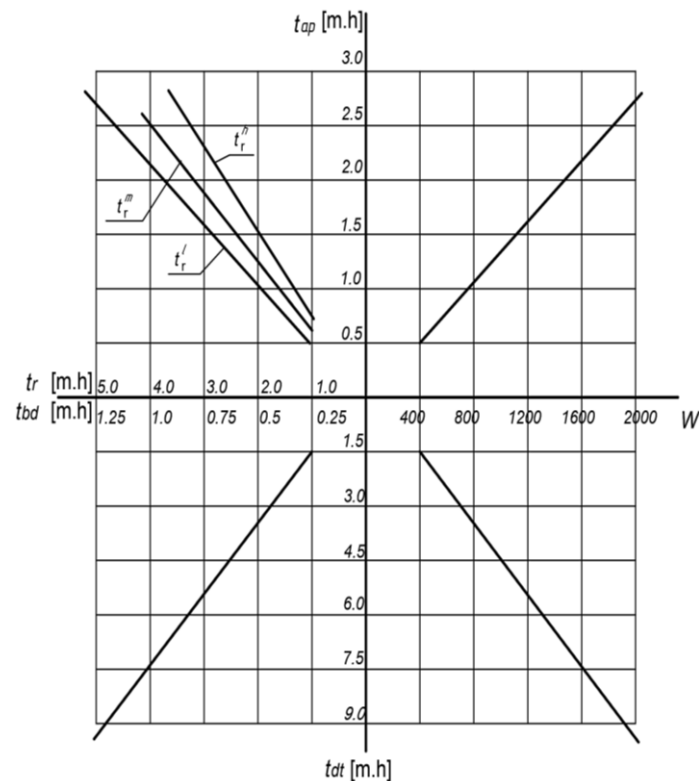


Fig.7: Nomogram for determining the labor intensity  $t_i$  of the machine set for asphalt concrete pavement construction.

$$[t] = 2.319 \text{ machine-hours.}$$

$$[t] = 2.34 \text{ machine-hours.}$$

5. The calculation of the normative labor intensity  $[t]$  for heavy-type compaction machines weighing more than 14 t. The results of the chronometric measurement of the average speed of the heavy-type roller are presented in Table 14.

The calculation of the hourly operational productivity of a heavy-type roller is calculated using Eq. (8):

$$P_h^o = 392.31 \text{ m}^2/\text{h.}$$

Then, the normative labor intensity  $[t]$  of the heavy-type roller is equal to:

6. The calculation of the normative labor intensity  $[t]$  of the bitumen distributor with a tank capacity  $q_t = 7.0 \text{ m}^3$ .

The calculation of the hourly productivity of the bitumen distributor is determined using the formula:

$$P_h^o = \frac{q_{dt} * k_i * k_T}{\frac{2L}{V} + t_f + t_d} = 1.136, \text{ m}^3/\text{h.}$$

Then, the normative labor intensity  $[t]$  of the bitumen distributor is defined as:

$$[t] = \frac{[V] * P}{P_h^o} = 0.62 \text{ machine-hours.}$$

where  $P$  is the norm of bitumen consumption,  $P = 0.7 \text{ l/m}^2$ .

**Results:** The results of the calculations for the formed rational set of machines for the construction of asphalt concrete pavement in different work volume measurements are presented in Table 15.

The developed nomogram for determining the labor intensity of the machine set for asphalt concrete pavement construction is presented in Fig.7.

The presented nomogram, designed to determine the labor intensity of a rational machine set configured according to

**Table 14:** Results of the chronometric measurement of the average operating speed of the heavy-type roller, model DYNAPAC CC 501.

№	Grip length $l_e, \text{ m}$	Duration of passage $t, \text{ sec}$	Operating speed		Average operating speed
			$V_o, \text{ m/s}$	$V_o, \text{ km/h}$	$V_o^{avg}, \text{ km/h}$
1		29	1.72	6.49	
2		26	1.92	6.91	
3		25	2.00	7.20	
4	50	29	1.72	6.19	6.483
5		27	1.85	6.66	
6		26	1.92	6.81	
7		29	1.72	6.19	
8		27	1.85	6.66	
9		28	1.79	6.14	
10		29	1.72	6.19	
11		30	1.67	6.01	
12		28	1.79	6.44	

**Table 15:** Normative labor intensities of the rational machine set for asphalt concrete pavement construction.

№	Machine name	Main parameter	Normative measurements, $\text{m}^2$									
			400	600	800	1000	1200	1400	1600	1800	2000	
1	Asphalt paver	3.5-8.5 m	0.56	0.85	1.13	1.41	1.69	1.97	2.26	2.54	2.82	
2	Light-type roller	Up to 6.0t	0.68	1.02	1.35	1.69	2.03	2.37	2.70	3.04	3.38	
3	Medium-type roller	8-12 t	0.92	1.39	1.85	2.31	2.77	3.23	3.70	4.16	4.62	
4	Heavy pneumatic rollers	More than 14.0 t	1.02	1.53	2.04	2.55	3.06	3.57	4.08	4.59	5.10	
5	Bitumen distributor	7000 l	0.25	0.37	0.50	0.62	0.74	0.87	0.99	1.12	1.24	
6	Dump truck	More than 20.0 t	1.87	2.81	3.74	4.68	5.62	6.55	7.49	8.42	9.36	

the technological process of asphalt-concrete pavement construction, allows one to determine and establish the labor intensity values of each road-construction machine included in that set. For a normatively established volume  $[W]$  of asphalt-concrete pavement works, the developed nomogram enables the determination of the labor intensity of each technological machine in the set: asphalt paver ( $t_{ap}$ ), bitumen distributor ( $t_{bd}$ ), road rollers ( $t_r$ ) subdivided by type (light  $t_r^h$ ,

medium  $t_r^m$ , heavy  $t_r^l$ ), and dump trucks ( $t_{dt}$ ).

**5. Conclusion**

Within the framework of this study, a machine system for the complex mechanized construction of highway elements was developed, encompassing a nomenclature of equipment aligned with the technological process. A methodology for calculating a rational machine set based on normative output

indicators was proposed, and normative labor intensity values were established for sets employed in the construction of the roadbed, gravel and crushed stone bases, as well as asphalt concrete pavement. Furthermore, algorithms for determining equipment requirements and nomograms for forming rational sets at each stage of road construction were developed.

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### Conflict of Interest

There is no conflict of interest.

### Supporting Information

Not applicable.

### CRedit Statement

**Zakir Maksudov:** Ideas, Formulation or Evolution of overarching research goals and Aims; **Kamoliddin Rustamov:** Management activities to annotate (produce metadata), Scrub data and maintain research data (including software code, where it is necessary for interpreting the data itself) for initial use and later reuse; **Tavbay Khankelov:** Application of statistical, Mathematical, Computational, or Other formal techniques to analyze or Synthesize study data; **Sherzod Khudainazarov:** Acquisition of the financial support for the project leading to this publication; **Mavlyan Kudaybergenov:** Conducting a research and investigation process, Specifically performing the experiments, or Data/Evidence collection; **Zebo Khalimova:** Development or design of methodology, Creation of models; **Sharofiddin Pirnaev:** Management and Coordination responsibility for the research activity planning and execution; **Gulxayo Niyazova:** Provision of study materials, Reagents, Materials, Patients, Laboratory samples, Animals, Instrumentation, Computing resources, or other analysis tools; **Kamola Karimova:** Preparation, Creation and/or presentation of the published work, Specifically visualization/Data presentation.

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