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ECONOMIC INDICATORS OF ROAD SURFACES RECONSTRUCTIONS IN THE WORLD USING NON-WASTE TECHNOLOGY

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The article describes the cost formation of restoration of road surfaces using the methods of replacing and processing the damaged layers. There is a mathematical model of cost of the one unit of production including the cost of building materials with delivery. The estimation of the total cost of repairs in the variable amount using the technology of full replacement of the surface and processing technology of the 50% of the material on the site.

Keywords: *pavement; repair; processing; cost of unit; delivery price; non-waste technology.*

1. Introduction

Costs of building and reconstruction of roads are steadily growing. Total length of paved roads is increasing, the technology of production is improving and the costs of construction materials production are also growing. Average life of Russian roads is about 10–13 years. For comparison, in China and the developed European countries – 20 years, in the US and Germany is up to 30 years. The average cost of building of 1 kilometer of highway in Russia is 2–3 times lower than in Germany and the United States. The cost of individual construction projects can differ by 20–30 times.

The comparison is indicative, in various countries there are different factors affecting the total cost: the costs structure of construction and installation works; design standards of geometric elements of road; rules for design loads and model construction pavements; the conditions of highways construction (terrain, climate). The average costs of building of 1 kilometer of highway in different countries are given in Table 1.

Table 1.

The average costs of building of 1 kilometer of highway in different countries

№	Country	The cost of 1 km strip not including the VAT, mln rubles		
		Average	Minimal	Maximal
1	Russia	41	30	73
2	USA	72	20	166
3	China	35	42	92
4	Canada	82	65	185
5	Germany	122	80	162
6	Finland	40	22	66
7	Spain	50	30	76
8	France	101	73	174

High-speed and high-quality construction of roads requires high technology and high-tech equipment. Reducing the cost of restoration of the damaged road surfaces is achieved through the use of new means of mechanization and processing technology of asphalt concrete material layer [3]. The volumes of recycled road surfaces are constantly growing [5]. Non-waste technology is provided by recycling of the existing pavement material cyclically using asphalt mixing plants or continuously by means of special technological complexes – «recyclers». Cyclical cold processing is a set of operations implemented by the technological complex: road milling machine, wheel loader, mixing machine, tipper for material transportation, asphalt paver, road roller.

Analysis of the enterprise economic mechanism functioning at all stages of the production process helps to increase the competitiveness of products. Reduction of the cost of road construction works is the main feature that leads to the increase of the competitiveness of organizations, improves the efficiency of enterprises and profitability. Reducing the cost of construction, repair and reconstruction of road surfaces is provided at the project planning stage, due to the optimization of complex mechanization, optimization of parameters and operating modes of individual units. Dislocation of asphalt mixing equipment considering the working place determines the means of mechanization.

The cost of restoring of the road surface made up of the machine-hour cost and the cost of construction materials delivered to the work site.

$$C_{ЕП} = \frac{C_{МЧ}}{П} + C_{МД}, \text{ rubles/m}^3, \quad (1)$$

$C_{МЧ}$ – the cost of machine-hour, rubles/hour
$П$ – technical complex capacity, m^3/hour
$C_{МД}$ – the cost of building material delivery, rubles/m^3

To estimate the cost of road surface reconstruction works using non-waste technologies there are discussed several ways to implement the recycling process – 1) on the remote mixing equipment (stationary/mobile plant/asphalt mixing plant); 2) using the «recycler» in process of work while removal/installation surfaces in conjunction with machinery for feeding a binder and/or water-cement slurry. In the first case for transporting materials between the cycles used tippers and wheel loaders. In both cases, there is a pre-set percentage of the material in the recycling of the new mixture.

2. Calculating the machine-hour cost

Calculating the machine-hour cost of the «recycler» (refiner) of pavement, road milling machine and paver includes calculation of the following types of costs: depreciation, labor costs of drivers and mechanics, the cost of fuel and lubricants for construction machinery, the cost of the hydraulic fluid, the cost of tires, the cost of relocation of the machine, the costs for maintenance and repair. Cost of machine-hour is defined as:

$$C_{МЧ} = C_{А} + C_{ОТ} + C_{ГСМ} + C_{ГЖ} + C_{ШГ} + C_{ПЕР} + C_{ТОР}, \text{ rubles/hour} \quad (2)$$

Depreciation depends on the value of purchased machines and annual operating mode, which establish monthly depreciation rate and the depreciation of 1 machine-hour. Labor costs of drivers and mechanics are calculated considering the employee's hourly rate with premiums and insurance premiums. POL (petroleum oil lubricants) costs of machinery are determined by the cost of materials and standards of fuel consumption in liters per one machine-hour. Costs of hydraulic fluid depend on the capacity of the hydraulic system, the hydraulic fluid density, complete replacement frequency (times/year) and fluid flow rates per one machine-hour. Calculation of the cost of tire of considers the average annual mileage of the car, tire price, the cost factor in the tire delivery, as well as the cost of norms for the restoration and repair of tires considering a normative mileage. Costs for relocation of a machine on a trailer depend on the fuel consumption per 100 km, fuel price in the region. Relocation of machinery is available under its own power. Costs on maintenance are based on the estimated replacement costs, balance of the working time and annual costs.

The level of machine-hour costs of mechanization on expenditure is presented in Table 2.

Table 2.

Calculation of machine-hour costs of road machines

Expenditure	Level of mechanization costs, ruble/hour		
	Milling machine W2000	Paver Vogele super 1800-2	«Recycler»WR 2000
Depreciation	1684,66	2059,6	4350,58
Labor costs of drivers and mechanics	273,45	273,45	215,12
POL costs of construction machines and mechanisms **	1729,39	501,42	1245,02
Cost of hydraulic fluid	132,77	137,2	141,62
Tires expenditures	-	-	84,74
The cost of relocation of the machine on trailer	78,41	78,41	78,41/866,58*
Maintenance	1768,9	1213,2	2020,75
Total	5666 rub/h	4264 rub/h	8923 rub/h

* – relocation under its own power.

Constructional and estimated productivity. Maximum technical productivity is established by minimizing the duration of work operations and machine cycles that are considered in [1, 2]. At the stage of pre-calculations for estimating the road surface restoration costs used construction productivity of the complex which is determined on the basis of technical specifications and recommended modes of work:

$$П = 60 \cdot B \cdot h \cdot V_i, \text{ m}^3/\text{h};$$

B – width of the road surface, m;

h – depth of the layer, m;

V_i – speed of machinery arriving, machine/minute.

3. Calculations of the material delivery costs

Cost of construction material delivery is calculated considering specific transportation conditions of individual components and asphalt mixtures according to the formula:

$$C_{МД} = \sum_{i=1}^{n} \left(C_М + C_Д\right)_i, \text{ rubles/m}^3, \quad (3)$$

$C_{МЧ}$ – cost of i-th material, ruble/m³;

$C_Д$ – delivery cost of i-th material, ruble/m³.

Delivery cost of asphalt mixture or the i-th component of the mixture (rubble, sand, asphalt emulsion, cement, lime, water, etc.) by transport is determined by the formula:

$$C_Д = \frac{C_{МЧД}}{П_Д} = \frac{C_{МЧД} \cdot l}{Q_{ТС} \cdot V_{ТС}}, \text{ rubles/m}^3, \quad (4)$$

$C_{МЧД}$ – machine-hour cost of transport, ruble/hour;

$П_Д$ – transport productivity, m³/hour;

l – transportation distance, m;

$Q_{ТС}$ – volume of transport, m³;

$V_{ТС}$ – speed of transport, m/hour.

Based on calculations (3) (4):

$$C_{МД} = \sum_{i=1}^{n} \left(C_{МДii} \right)_i = \sum_{i=1}^{n} \left(C_{Mi} + \frac{C_{МЧД} \cdot l}{Q_{TC} \cdot V_{TC}} \right)_i \text{, rubles/m}^3, \quad (5)$$

In the case of delivery of the required volume of material several times the total cost of m^3 is calculated according to the formula:

$$C_{ДОбщая} = \frac{C_{МЧД} \cdot l}{Q_{TC} \cdot V_{TC}} \cdot N = \frac{C_{МЧД} \cdot l \cdot Q_M}{Q_{TC}^2 \cdot V_{TC}} \text{, rubles/m}^3, \quad (6)$$

$N = \dfrac{Q_M}{Q_{TC}}$ – quantity of times during the delivery;

Q_M – total material volume, m^3;

Q_{TC} – volume of transport, m^3.

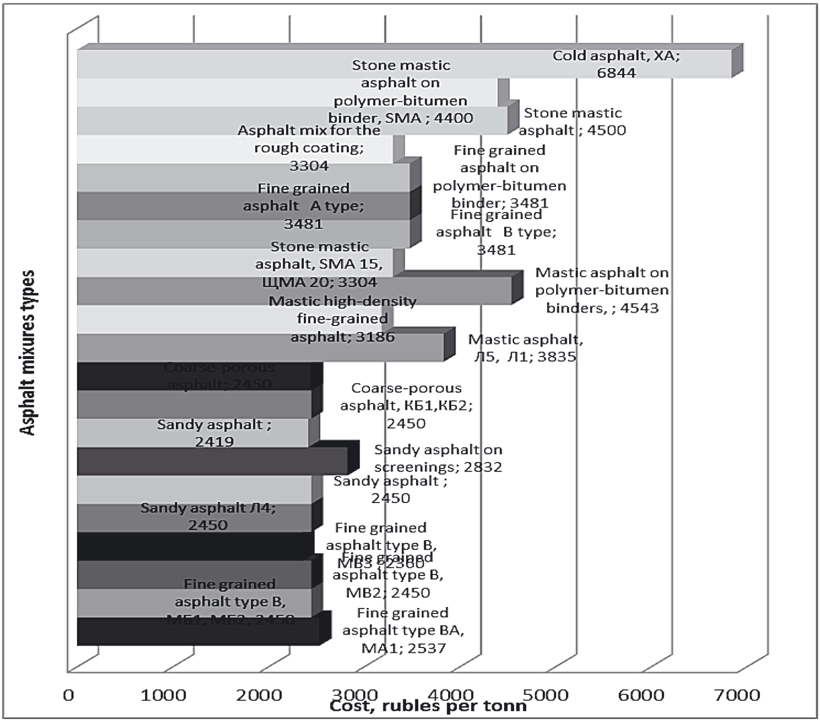

Fig. 1. Cost of 1 tone of asphalt mixture

Figure 1 shows the values of cost of the various types of asphalt mix, including cold asphalt, mastic asphalt on polymer-bitumen binders, stone mastic asphalt (SMA) on a different binder.

The ability to re-use and the desired composition of the asphalt mixtures of materials in processing of road surfaces are determined by the laboratory analysis [4]. Then, the analysis of volumes and transportation conditions of necessary components and mixtures of materials is taking place (Table 3).

Table 3.

Material and mixture component data

№	Component of the mixture	Price rub/ m^3	Total material volume, m^3	Transportation distance, m	Transportation speed allowed, km/h
1	Gravel	1500	10 000	10 000	No limits
2	Sand	800	100		60
3	Bitumen	19 000*	10		60
4	Mixture	10 000**	120		

* – The average density of bitumen is 0,95-1,50 g / cm3, the average density of bitumen emulsion – 1 g / cm3 = 1000 kg / m3, the price is 19 rubles / kg.

** – The average density of asphalt mix is 2500 kg / m3, the price Stone mastic asphalt mix - 4000 RUR / tone.

Table. 3 helps to calculate the total cost of materials, work mechanization and implementation of the project. On the basis of (6) there are determined total costs of materials:

$$C_{МД}^{\Sigma} = \sum_{i=1}^{n} \left(C_{МДi} \cdot Q_{Mi} \right), \text{ rubles,}$$

$$C_{МД}^{\Sigma} = \sum_{i=1}^{n} \left(C_{Mi} \cdot Q_{Mi} + \frac{C_{МЧ} \cdot l \cdot Q_{Mi}^{2}}{Q_{TC}^{2} \cdot V_{TC}} \right), \text{ rubles.}$$

Total costs of the work:

$$C_{ЕП} = \frac{C_{МЧ}}{П} \cdot Q_{РАБОТ}.$$

Total project costs:

$$C_{ЕП}^{\Sigma} = \frac{C_{МЧ}}{П} \cdot Q_{РАБОТ} + \sum_{i=1}^{n} \left(C_{Mi} \cdot Q_{Mi} + \frac{C_{МЧ} \cdot l \cdot Q_{Mi}^{2}}{Q_{TC}^{2} \cdot V_{TC}} \right), \text{ rubles}$$

Evaluation of pavement restoration costs

Considering the layer width of 2m and depth of 0.1m the speed road milling machine is equal to the maximum speed of paving the mixture considering the working hours of pre-sealing aggregate:

$$V_Ф = V_У = 10 \ м/мин.$$

The average maximum speed of milling and mixing unit recycler arrival is: $V_C = 5 \ м/мин.$

Replacing and recycling the layer width of 2m and the depth of 0.1 m structural productivity of road milling machine $П_Ф$ and paver $П_У$ comparable:

$$П = П_У = П_Ф;$$

$$П = 60 \cdot B \cdot h \cdot V_i = 60 \cdot 2 \cdot 0{,}1 \cdot 10 = 120 \, {м^3}/{ч};$$

The damaged material is removing from the surface, transported from the work site or transported to the asphalt plant for processing. New asphalt concrete mixture is transported from the plant back for paving.

$$C_{ЕП} = C_{ЕПФ} + C_{ЕПУ} + C_{МД} = \frac{C_{МЧФ} + C_{МЧУ}}{П} + C_{МД}, \text{ rubles/m}^3.$$

At equal productivity unit cost of production of milling plant and paver is based on the data of Table 1 under the formula:

$$C_{ЕПФ} + C_{ЕПУ} = \frac{C_{МЧФ} + C_{МЧУ}}{П}, \text{ rubles/m}^3.$$

Analyzing the nature of the changes in unit costs for the given conditions of material delivery (Table 2) at a variable transportation distance l = var (Figure 3):

$C_{МЧД}$ = 2000, ruble/hour; $C_М$ = 10000, ruble/m³; Q_{TC} = 15, m³; V_{TC} = 45, km/h.

Provided that there is no removal of damaged material, the delivery cost of the material is determined by the ratio:

$$C_{МД} = \sum_{i=1}^{n} \left(C_{Mi} + \frac{C_{МЧД} \cdot l}{Q_{TC} \cdot V_{TC}} \right)_i = 10000 + \frac{2000 \cdot l}{15 \cdot 45000} = 10000 + 2{,}96 \cdot 10^{-3} \cdot l$$

Cost of production units for milling-paving material in a volume of 120 m^3:

$$C_{ЕП} = \frac{5666 + 4264}{120} + 10000 + 2{,}96 \cdot 10^{-3} \cdot l, \text{ rubles/m}^3;$$

$$C_{ЕП} = 82{,}75 + 10000 + 2{,}96 \cdot 10^{-3} \cdot l, \text{ rubles/m}^3.$$

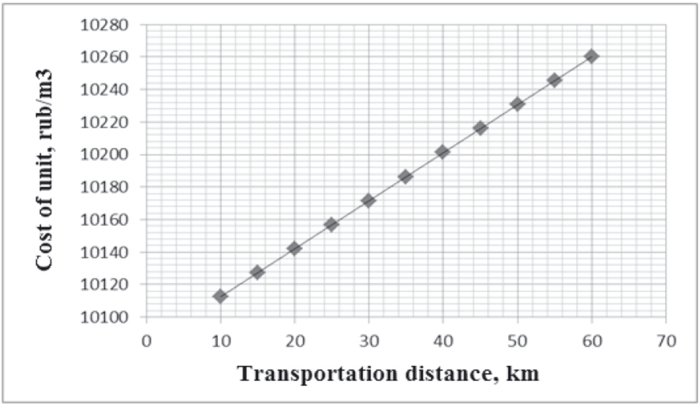

Fig. 3. Increase of the replacement cost of a 120 m^3 of asphalt surface with increasing transportation distance of a new asphalt mix

An analysis of the graph in Figure 3 shows that the unit cost of production of road milling machine and paver is largely determined by the price of asphalt mix. The volumes of work have little effect on the cost of replacing a 1 m^3 of material.

There are two cases:

Case 1: Replacement of the surface layer, removal of the damaged layer by the road milling machine. New asphalt concrete mixture is brought up from the factory and paved by the paver;

Case 2: Replacement of the surface layer, removal of damaged layer. Some material is processed on place, mixed with new asphalt mixture, which is brought up from the factory and the resulting mixture is placed in coating. All process steps are carried out by one machine.

To assess the cost-effectiveness of the compared technologies, consider the overall changings of replacement costs of the 1000 m3. Total costs for reconstruction work in the volume of 1000 m3 for the technology of complete replacement of the asphalt pavement:

$$C_{ЕП}^{\Sigma} = \frac{C_{МЧ}}{П} \cdot Q_{РАБОТ} + \sum_{i=1}^{n} \left(C_{Mi} \cdot Q_{Mi} + \frac{C_{МЧ} \cdot l \cdot Q_{Mi}^{2}}{Q_{TC}^{2} \cdot V_{TC}} \right), \text{ rubles.}$$

$$C_{ЕП}^{\Sigma} = 10082750 + 197{,}5 \cdot l.$$

Total costs for reconstruction in the volume of 1000 m3 at 50% of the processing technology of asphalt pavement:

$$C_{ЕП}^{\Sigma} = 5148700 + 49{,}38 \cdot l.$$

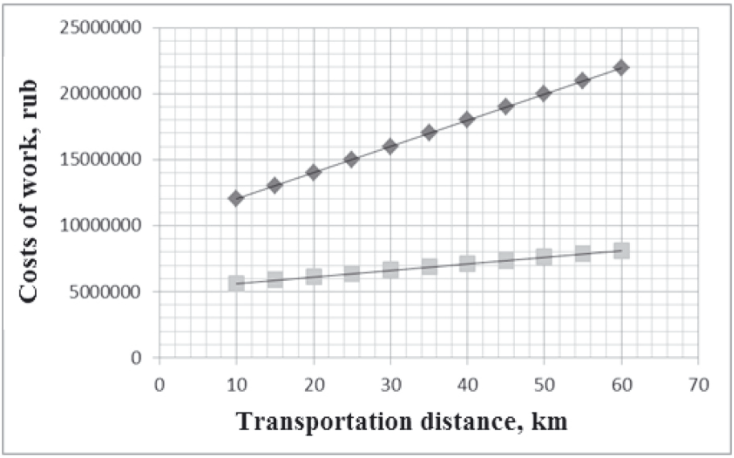

Fig. 4. Comparison of the cost of repairs to a volume of 1000 m^3 using the conventional method (1) and with the method of processing and reuse of 50% damaged material (2)

An analysis of the graph in Figure 4 shows that an increase in repair cost of recycled material occurs at a lower intensity compared to the technology of full replacement of coating layers. The intensity of the increase is graphically shown in Figure 5.

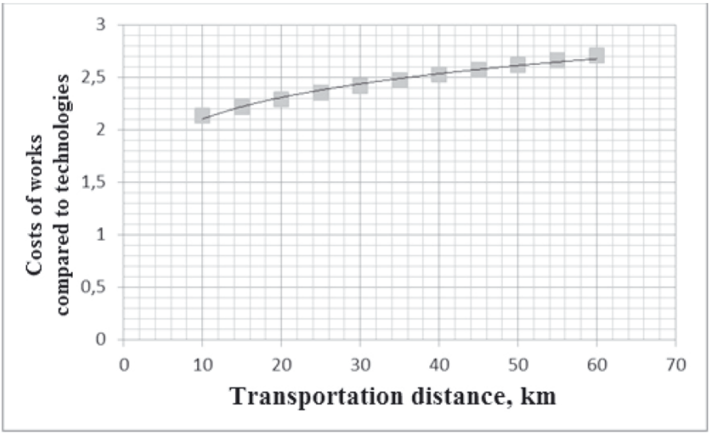

Fig. 5. Analysis of the cost of repairs to a volume of 1000 m3 using the conventional method and with the method of processing and reuse of 50% damaged material

Conclusion

In the planning phase of capital investments for restoration of the road surface using the non-waste technology cost savings are achieved through the rational distribution of construction sites relative to the base production / processing of road-building material. In certain operating conditions, processing technologies became priority in the repair and reconstruction of road surfaces.

Unit cost of coating layers repairing is determined primarily by the cost of asphalt mix. The dynamics of the direct total cost of repairs is determined by the degree of re-use and workload.

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