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Integrated efficiency assessment of road reconditioning

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ABSTRACT

The paper dwells on the issues of improving traffic quality and safety; analyses domestic and foreign experience of road reconditioning by applying modern methods. It assessed the operating usefulness of modern repair methods (depending on the condition of road pavement before repair). The minimum warranty service life of pavements was established by analytic and experimental way after applying the relevant method of repair. The algorithm of operational and economic feasibility of repair work is designed and grounded on the basis of domestic and foreign methods of quality assessment of repairs. The proposed method considers not only condition of pavement before repair and cost of repairs but also effects of improving traffic quality and safety and prolonging road service life. The method also considers climatic conditions of regions that allows more reliably to predict operational efficiency of repair work. The main feature of this method is ability at a stage of substantiation of engineering and technical decisions to predict operational and economic benefits of using one or another option of roadwork and on the basis of economic-mathematical modelling to show which option will be more expedient and efficient.

Content

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1. Introduction

Automobile road is set of complex engineering constructions. Road needs continual timely fulfillment of works on the upkeep and repair of basic technical elements. Domestic and foreign experience of experts in road maintenance shows that untimely fulfillment of works leads to the accumulation of defects and deformations and to the premature failure of pavement construction, roadbed and other elements of road [1–6]. The result of the accumulation of defects and deformations is premature failure of a road design and is reduction of period between repairs as well as increase in expenditure on upkeep and repair of road facilities.

The south of the Russian Far East refers to the region with an extremely difficult monsoon climate which is characterized by excessive rainfall in summer, hot summers and cold winters, and deep seasonal freezing of the soil. An experience of road design and construction in the south of the Russian Far East shows that period between repairs of roads is significantly less than common standards [6, 7]. There is no unambiguous solution of increase inter maintenance period of roads for not only difficult conditions of the south of the Russian Far East but for Russia and the whole world community as well [5, 8–15].

2. Methods

It is reliably established that the most important aspect of road's life is stability of work system "working layer of the roadbed – road pavement" [3, 5, 8]. In so doing the principal climatic and technogenic factors affecting the system's efficiency are uneven temperature mode of work, periodical moistening by surface and subterranean waters, deep seasonal freezing, uneven thaw of structural layers of pavement, dynamic and static influence of transport loading, fatigue changes of materials of construction.

The modern development of road construction and road repair technique allows to eliminate one and the same set of defects of covering in several ways but finally quality of renovated pavement will not be the same for all methods of repair [3, 11, 14–16]. For evaluating operational expediency and efficiency of work repair it's necessary to take into account many diversified factors such as climatic conditions, seasonality of works, processability, laboriousness, transport-operational condition of the road before and after repair, road operation mode, traffic volume and etc.

Besides various methods and technologies of road reconditioning it's necessary to take into account the possibility of applying of modern building materials [17–20], which are not only increasing period between repairs and slowing down the development of defects and deformations but also are reducing the value of road construction and reconditioning.

The analyze of domestic and foreign experience of road construction, reconstruction and maintenance [3, 8, 14, 15, 19] as well as the survey of more than 100 road sections of the south of the Russian Far East (total length – more than 1000 km) allows to formulate the principle efficiency assessment of works on overhaul, repair and reconstruction of road pavement [21, 22]:

"The method of repair of road pavement, ensuring maximum period of effective work of construction and cost minimization, will called efficient for the actual level of transport and operational combination of the road".

In Russia, there is a methodology developed by Professor A.P. Vasilyev for evaluating of transport and operational condition of the roads. It is when road condition is estimated by the total value of the coefficient of calculation speed – Ccs [23]. In particular for assessing the road condition it is possible to use the coefficient responsible for condition and strength of pavement – Ccs 8. Also for a technical and economic comparison of options of pavement it is applied the methodology that takes into account cost of works on operation and repair of pavements during the entire period between repairs with the residual value [24, 25].

In Europe and in USA for assessment of operational road condition Pavement Condition Index (PCI) is applied. It reflects the level of the defect. Repair cost depends on methods and means of roadwork and provides for 1 m^2 of renovated pavement.

Both methods of assessment of operational road condition rely on a scoring of coverage condition, but don't provide the clear boundaries of applying one or another method and/or technology of repairs (for repair, overhaul and reconstruction of roads). That is why works on applying assessment of methods of works (depending on operational condition of covering before repairs) were carried out [21, 22]. The results are presented in Table 1.

For each level of operating condition of pavement, it is possible to apply some repair techniques that have a plenty of design decisions. Therefore, the task of finding of efficient repair method is of a probabilistic nature. The cost of work must also be considered for thorough evaluation of quality of works. It follows that task of efficiency assessment of repairs is not linear. The mathematical interpretation task of efficiency assessment of pavement repair is as follows:

It's necessary to find one of the many repair methods which will provide the best ratio of increase of pavement performance (no less than minimum allowed values) and decrease of expenses for production of works, depending on actual operational condition of pavement.

Table 1. Applicability of methods of works on repair of road pavement

The method of repair of pavement	The possibility of applying the repair method depending on level of operational condition of pavement			
	Excellent *Ccs8* 5.0-4.1 *PCI* 100-81	Good *Ccs8* 4.0-3.1 *PCI* 80-61	Satisfactory *Ccs8* 3.0-2.1 *PCI* 60-41	Unsatisfactory *Ccs8* ≥ 2.0 *PCI* ≥ 40
Crack closure	+	+	-	-
Jet injection method	+	+	-	-
Surface mat-forming treatment	+	+	-	-
Protective coat (Slurry seal)	-	+	+	-
Hot-mix wearing courses (thin and ultra - thin layers)	-	+	+	-
Thermoprofiling (hot recovery)	-	-	+	+
Cold recovery	-	-	+	+
Pavement reconstruction	-	-	-	+

Thus, the task of efficiency assessment of pavement repair has the form:

$$\begin{cases} minmax\ PRQ(QER; EER) \\ QER \to max \\ QER \in D \\ EER \to min \\ EER \in D \end{cases} \quad (1)$$

The integrated indicator *PRQ* (Pavement Repair Quality) is individually determined for each option of road reconditioning. It reflects non-linear dependence between *QER* (Operational Efficiency Renovations) and *EER* (Economic Efficiency Of Renovations). Besides, *PRQ* takes into account *PEWP* (Period of Efficient Work of Pavement).

QER is determined from this condition:

$$QER = PEWP(SPS + PQI) \quad (2)$$

The coefficient of *SPS* (Stock Pavement Strength) is mathematically determined by method of Sectoral Road Standards *(SRS)* or by means of experimental measures by static and dynamic loading. As work efficiency is evaluated for the future (before construction), then mathematical way is more acceptable decision.

It is necessary for definition of *PEWP*:

$$PEWP = (T_{WSLP}/T_{PBRP})^{\beta} \quad (3)$$

T_{PBRP} (Period Between Repairs of Pavements) is established according to normative and technical documents for the country or the region individually.

T_{WSLP} (Warranty Service Iife of Pavements) determines the time during which operational efficiency of pavement will be correspond to normative and technical documentation and will be in perfect operational condition. T_{WSLP} index depends on work method and quality of building materials. Theoretically TWSLP may be [26] Identified by method or accept expectable service life of pavement [15]. Analytically determined the minimum values of index TWSLP for each pavement repair method. The WSLP values (for roads situated in European Russia) are given in table 2. It should be noticed that in the table 2 the values in brackets are indicated for methods, the use of which is not be cost-effective for appropriate level of operational condition.

In defining *PEWP* it is necessary to take into account climatic operating conditions of pavement, which are characterized by the coefficient of heterogeneity β. The β-values are empirically determined for Russian territory and depend on climatic zone for road building and are given in table 3.

As road safety and quality directly depend on pavement condition, so it needs to take into account effects of Pavement Quality Improvement (PQI) to evaluate operating condition of road.

$$PQI = \prod K_i \quad (4)$$

PQI-index takes into consideration the common resultant effect of change of operating pavement condition arising from the removal of one or another pavement defect and from the improvement of road safety and quality. Coefficients *C1–C12* consider the change of one certain condition of pavement. These values are given in tables 4–5.

Table 2. The minimum warranty service life of pavements T_{WSLP}

The method of repair of pavement	The minimum warranty service life of pavements depending on operational condition of pavement before repair (year)			
	Excellent *Ccs8* 5.0-4.1 *PCI* 100-81	Good *Ccs8* 4.0-3.1 *PCI* 80-61	Satisfactory *Ccs8* 3.0-2.1 *PCI* 60-41	Unsatisfactory *Ccs8* ≥ 2.0 *PCI* ≥ 40
Crack closure	1.5	1.25	-	-
Jet injection method	2.0	1.5	-	-
Surface mat-forming treatment	2.25	1.5	-	-
Protective coat (Slurry seal)	(2.5)	2	1.75	-
Hot-mix wearing courses (thin and ultra-thin layers)	(2.5)	2.25	1.75	-
Thermoprofiling (hot recovery)	(4.5)	(4.0)	3.75	3.0
Cold recovery	(4.5)	(4.25)	4.0	3.5
Pavement reconstruction	(4.5)	(4.5)	(4.25)	4

Table 3. The values of the coefficient *β*

Climatic zone for road building	I	II	III	IV	V
Coefficient β	0.85	0.94	1.00	1.07	1.14

Table 4. Types of removed defects of pavement

Condition and characteristic of removing damage (on 1000 m^2)	Coefficient	Value
Cross single cracks, where crack width - up to 2 mm	*C1*	1.01
The same up to 5 mm		1.02
The same up to 10 mm		1.03
The same more than 10 mm		1.05
Longitudinal cracks, where crack width - up to 2 mm	*C2*	1.02
The same up to 5 mm		1.03
The same up to 10 mm		1.05
The same more than 10 mm		1.07
Cracks in road base courses	*C3*	1.20
Cracking in area of up to 10 m^2	*C4*	1.05
The same up to 50 m^2		1.07
The same more than 50 m^2		1.10
Rutting with an average depth of rut up to 10 mm	*C5*	1.05
The same up to 20 mm		1.07
The same up to 30 mm		1.10
The same up to 40 mm		1.12
The same up to 50 mm		1.15
The same more than 50 mm		1.20
Subsidence depression (frost heave) in area of up to 10 m^2	*C6*	1.10
The same up to 50 m^2		1.15
The same more than 50 m^2		1.20
Pavement break in area of up to 10 m^2	*C7*	1.20
The same up to 50 m^2		1.30
The same more than 50 m^2		1.40
Potholes with the total area of up to10 m^2	*C8*	1.10
The same up to 50 m^2		1.20
The same more than 50 m^2		1.25
Cross waves, shifts	*C9*	1.10

Table 5. Performance

Road performance	Coefficient	Value
Improvement of grip of wheels (wheel contact)	*C10*	1.10
Restoration of cross-section	*C11*	1.15
Improvement of longitudinal evenness	*C12*	1.10

The value of corresponding coefficient *C* is assumed to be 1.00 in case the method of repair can't remove defect of pavement or restore road performance.

The value of *EER* on the use of each method of repair work and each option of applying one and the same method (designs of pavement, thickness of overlays, building materials and etc.) is determined by individual estimate calculation on 1000 m^2 of the pavement renovated. As a rule, the value of *EER* is calculated by enlarged index of estimated cost but full estimating is permitted.

It is experimentally established that for finding an optimal solution of a task (1) it's necessary to consider at least 5 options, which will belong to field of admissible decisions *D*, i.e. will be competitive towards one another. Competitive option may be considered only one which surpass a minimum of 3 another options in one of index of quality and efficiency (for example: out of 5 options - those ones will be competitive if No. 1 – by the *QER* – 1 place, by *the EER* – 5 place, No. 2 – by *the QER* – 4 place, by the *EER* – 3 place and etc. But if No. 2 – by the *QER* – 4 place and by the *EER* – 4 place, then No. 2 is not competitive).

The indicator *PQR* must be calculated for each competitive option:

$$PRQ = QER \cdot P_1 + EER \cdot P_2 \tag{5}$$

As the task (1) is not linear (criteria of efficiency aspires in different directions), then for the decision of task (5) it's necessary to determine the significance of coefficients *P1 and P2*, which depend on level of pavement condition and on applicability of the repair methods of pavement.

The values of coefficients *P1 and P2* were determined by expert estimates [21, 22].]. For this it was formed a group of leading experts in the field of road design, construction, reconditioning and reconstruction (on the territory of the south of the Russian Far East). The final values of coefficients *P1* and *P2* are given in table 6.

Table 6. Recommended values of weights *P1 and P2*

Transport and operational characteristics			Coefficients	
Pavement condition	*Ccs 8*	*PCI*	P_1	P_2
Excellent	5.0 … 4.1	100 … 81	0.383	0.617
Good	4.0 …3.1	80 … 61	0.553	0.447
Satisfactory	3.0 … 2.1	60 … 41	0.599	0.401
Unsatisfactory	2.0 and less	40 and less	0.701	0.299

As the indicators, *QER* and *EER* have different dimension, then the task (5) cannot be solved explicitly. The indicators need to be lead to one-dimensional value, i.e. so they need to be changed from 0 to 1. For this purpose, it is necessary to calculate the efficiency index by the following equations:

$$QERI = \frac{QER_{max} - QER}{QER_{max} - QER_{min}} \tag{6}$$

$$EERI = \frac{EER - EER_{min}}{EER_{mqx} - EER_{min}} \tag{7}$$

Transformations will not only lead both criteria – *QER* and *EER* – to one-dimension value but will also achieve that *QERI* (Operational Efficiency Renovations Index) and *EERI* (Economic Efficiency Of Renovations Index) aspire to optimum value. At the same time, *QERI* and *EERI* reflect the degree of approximation of result to optimum value, i.e. regardless of whether index aspires to maximum *QER* or to minimum *EER*, *QERI* and *EERI* both will aspire to minimum, because 0 is the best approximation to optimum value.

3. Results and Discussion

After performing all subsidiary and intermediate calculations and transformations for assessment of pavement repair efficiency it's necessary to calculate one integrated indicator which will evaluate the degree of approximation of design decision to absolutely optimum option.

That is why for each option it is necessary to determine the final PREI (Pavement Repair Efficiency Index):

$$PRQI = QERI \cdot P_1 + EERI \cdot P_2 \quad (8)$$

The developed method was used to justify expedience of method of cold recovery of pavement on the roads of the south of the Far East (Khabarovsky Krai).

According to a diagnostic survey, road network of Khabarovsky Krai is on average in a satisfactory condition (*Ccs* 8 = 2.8, *PCI* = 55). Eight options of design decision were suggested for road reconditioning, including two options of cold-application. The options are given in table 7.

Table 7. The options of design decision

Option's number	Option's description	*Criterion of effectiveness QER, unit*	Cost of repair of 1000 m^2 of pavement EER, rub.
No. 1	Protective coat (Slurry seal)	0.4413	482
No. 2	Wearing course of hot-mixed asphalt 5 cm of thickness (without removal of old pavement)	0.5138	884
No. 3	Wearing course of hot-mixed asphalt 6 cm of thickness (removal of 5 cm of old pavement)	0.5218	1157
No. 4	Wearing course of hot-mixed asphalt 5 cm of thickness (on the levelling course of hot-mixed asphalt up to 4 cm of thickness)	0.5782	1106
No. 5	Thermoprofiling at a depth of 5 cm with addition of new material (of hot-mixed asphalt)	1.2542	1375
No. 6	Cold recovery at a depth of 15 cm with hot-mixed asphalt application of 5 cm thickness	2.1260	1457
No. 7	Cold recovery at a depth of 25 cm with hot-mixed asphalt application of 5 cm thickness	2.1577	1915
No. 8	Pavement reconstruction (application of new base layers and road pavement)	2.9219	2751

All options of pavement repair (table 7) are competitive. Application of the option No. 8 is justified by the fact that it is the most common way of pavement renewal for Khabarovsky Krai. Method of thermoprofiling was added as an alternative to cold recovery method (but it also does not apply in Khabarovsky Krai). The results of the calculations are given in table 8.

Table 8. Efficiency of repair methods of pavement

	QER	*EER*	*QERI*	*EERI*	*PRQI*
Option No. 1	0.4413	482	1.000	0.000	0.5990
Option No. 2	0.5138	884	0.971	0.177	0.6525
Option No. 3	0.5218	1157	0.968	0.297	0.6989
Option No. 4	0.5782	1106	0.945	0.275	0.6762
Option No. 5	1.2542	1375	0.672	0.394	0.5605
Option No. 6	**2.1260**	**1457**	**0.321**	**0.430**	**0.3645**
Option No. 7	2.1577	1915	0.308	0.632	0.4378
Option No 8	2.9219	2751	0.000	1.000	0.4010

Thus, it was established that for Khabarovsky Krai from the economic and operational points of view the most efficient technique of road reconditioning is method of cold recovery of pavement. And the most expedient option is № 6 with less depth of recovery.

4. Conclusions

The developed method of integrated efficiency assessment of pavement repair allows:

- to determine (depending on operational condition of pavement before repair) a number of measures, which are more reasonable to apply for restoring of consumer properties of road;

- to give a balanced assessment of operational and economic efficiency of application of each variant of repair work, to exclude uncompetitive variants and to choose the most efficient technique;

- to avoid overspending of labor, material and financial resources and to extend design life of road as much as possible.

The developed method also has an undoubted advantage over existent domestic [23] and foreign [15] methods: ability at the stage of justification of engineering proposals to predict operational and economic benefits of using one or another variant of work production and on the basis of economic-mathematical modeling to say what variant will be the most expedient and efficient.

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Комплексная оценка эффективности ремонта автомобильных дорог

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ИНФОРМАЦИЯ О СТАТЬЕ	ИСТОРИЯ	КЛЮЧЕВЫЕ СЛОВА
doi: 10.18720/CUBS.58.1	Подана в редакцию: 09.03.2017	Автомобильная дорога; ремонт; покрытие; дорожная одежда; эффективность работ; экономико-математическая оценка.

АННОТАЦИЯ

В статье рассмотрены вопросы повышения качества и безопасности дорожного движения. Выполнен анализ отечественного и зарубежного опыта ремонта автомобильных дорог современными методами. Дана оценка эксплуатационной целесообразности применения современных методов ремонта, в зависимости от состояния дорожной одежды до ремонта. Аналитическим и экспериментальным путем установлены минимальные гарантийные сроки службы дорожной одежды, после применения соответствующего метода ремонта. На основе отечественных и зарубежных методов оценки качества ремонтных работ разработан и обоснован алгоритм определения эксплуатационной и экономической целесообразности ремонтных работ. Предложенный метод учитывает не только состояние дорожной одежды до ремонта и стоимость ремонтных работ, но и эффекты повышения качества и безопасности движения, а также так величину продления срока службы автомобильной дороги. Так же методика учитывает природно-климатические условия регионов, что позволяет более достоверно прогнозировать эксплуатационную эффективность ремонтных работ. Главной особенностью методики является способность на стадии обоснования инженерно-технических решений предсказать эксплуатационные и экономические выгоды от применения того или иного варианта производства работ и на основе методов экономико-математического моделирования сказать какой вариант будет наиболее целесообразным и эффективным.

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