

**UDC 629.4.02**M. I. KAPITSA<sup>1\*</sup>, O. M. HNENNYI<sup>2\*</sup>, D. V. BOBYR<sup>3\*</sup><sup>1\*</sup>Dep. «Locomotives», Dnipropetrovsk National University of Railway Transport named after Academician V. Lazaryan, Lazaryan St., 2, Dnipro, Ukraine, 49010, tel. +38 (0562) 33 19 61, e-mail m.i.kapitca@ua.fm, ORCID 0000-0002-3800-2920<sup>2\*</sup>Dep. «Economics and Management», Dnipropetrovsk National University of Railway Transport named after Academician V. Lazaryan, Lazaryan St., 2, Dnipro, Ukraine, 49010, tel. +38 (056) 373 15 80, e-mail oleggnennij@gmail.com, ORCID 0000-0002-2944-5105<sup>3\*</sup>Dep. «Locomotives», Dnipropetrovsk National University of Railway Transport named after Academician V. Lazaryan, Lazaryan St., 2, Dnipro, Ukraine, 49010, tel. +38 (0562) 33 19 61, e-mail dmitrob@ua.fm, 0000-0003-1441-3861**EFFICIENCY OF MODERNIZATION OF WHEEL-MOTOR BLOCKS USING ANTI-FRICTION TRACTION MOTOR SUPPORT BEARINGS**

**Purpose.** The use of anti-friction traction motor support bearings (TMSB) instead of plain friction traction motor support bearings is a priority direction of locomotive development both for newly constructed locomotives and for those in operation. The solution of the set tasks for introduction of wheel-motor blocks (WMB) with anti-friction bearings demanded the search for alternative variants and new technical solutions. The purpose of the article is to determine the feasibility of re-equipping the diesel locomotive wheel-motor blocks with anti-friction bearings through the life cycle calculation (*LCC*). **Methodology.** The procedure and criteria for assessing the economic efficiency of project (investment) proposals and investment projects approved by the Cabinet of Ministers of Ukraine envisage that the cost-effectiveness analysis of an investment project is carried out according to the following criteria: net present value, internal rate of return, discounted payback period and profitability index. The use of these criteria of economic efficiency fully corresponds to modern principles, theoretical-methodical approaches and world practice in evaluating the efficiency of investments. The evaluation of the technical and economic efficiency of the modernization of the diesel locomotive wheel-motor block is made on the basis of calculation and comparison of the following criteria: the net present value (*NPV*) of modernization, the internal rate of return (*IRR*), the profitability index (*PI*) and the discount payback period. **Findings.** The results of the calculations of the values of the main criteria show that the innovative project for the modernization of the locomotive provides a high level of economic efficiency. At the same time, the value of the discounted payback period of investments in modernization indicates that it is expedient to carry out this operation if the residual life of the upgraded locomotive of the M62 series is at least 15 months. **Originality.** Taking into account the specifics of the type of locomotive work in freight traffic, we developed a method to determine the individual components of the average annual economic effect of modernization of the diesel locomotive wheel-motor block, which includes saving of oil costs, repairing and servicing the diesel locomotive wheel-motor unit, as well as change of TMSB brass and saving fuel costs for traction. **Practical value.** The results of the work make it possible to determine the expediency of modernization of diesel locomotives taking into account the features and conditions of their operation and the specifics of modernization.

**Keywords:** diesel locomotive modernization; wheel-motor block; technical and economic efficiency; anti-friction bearings; life cycle

**Introduction**

The priority direction of the investment policy of PJSC «Ukrzaliznytsia» in the locomotive economy of Ukraine in recent years is to provide a quick, comprehensive renovation and optimization of the traction rolling stock structure. This is due to the fact that most of the traction rolling stock was procured and delivered to operation even in Soviet times. Analysis of the state of the operating fleet of the traction rolling stock of Ukrainian railways indicates that its wear is 97.1% [11]. As it

is known, the results of rail transport activity in general depend on the level of technical excellence and the state of the traction rolling stock, conditions of its operation, repair and maintenance systems [14, 15].

The traction rolling stock may be renewed due to the purchase of a new one and the modernization of the existing one. In both cases, this requires significant capital investments. It is also necessary to take into account that the return on investments in modernization of locomotives is 3-4 times faster than in their acquisition. Therefore, in the context of market relations and financial constraints, the problem of

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investment support for the renewal of the tractive rolling stock of the locomotive economy of Ukrainian railways is put forward at the level of problems of national importance, the solution of which directly affects the provision of national security.

During the last years, the Department of the Locomotive Economy has introduced a number of steps for modernization of the traction rolling stock, aimed at reducing the cost of repairs and fuel and lubricants in operation. Directions of accomplished and planned modernizations mainly concern the replacement of power equipment. However, no less effective direction of modernization of the traction rolling stock is the improvement of underframe design, namely the refitting of WMB from plain friction bearings to anti-friction bearings [2].

Anti-friction bearings have several advantages over plain friction bearings. The main advantage of anti-friction bearings in comparison with plain friction bearings is the lower energy consumption for the friction process (friction moment in ball bearings is approximately 3-6 times less than that of plain friction bearings [6, 12]).

All new foreign locomotives are equipped with anti-friction TMSB. Their implementation allows conducting the locomotive maintenance M-2 not every 3-4 days, but every 10-12 or more. It is the replenishment of the plain friction TMSB with axial oil that requires the need for such frequent maintenance M-2 for 90% of the locomotive fleet [12].

Estimated resource of anti-friction TMSB is not less than 5 million km of locomotive mileage. Application of wheel-motor blocks with anti-friction TMSB increases the cost of a locomotive, but pay-back is achieved due to the presence of the following factors:

- Exclusion from the technological process of servicing and repair of WMB of axial oils and the necessity of their seasonal change;
- Cost reduction for technical maintenance and repairs of the WMB with anti-friction TMSB;
- Increase of reliability and service life of traction gear and traction electric motor (TEM) due to absence of distortion caused by wear of brass inserts of plain friction traction motor support bearings;
- Increase in the wheel set life cycle due to the lack of wear of the journals under the plain friction TMSB;

- Absence of the need to pay fines for environmental pollution by eliminating the leakage of axial oils on the permanent way;

- Increase in the locomotive profitability – increase in the use of power for draft, increase in efficiency by reducing the main resistance of the locomotive, and, accordingly, reducing fuel consumption for traction from 2% to 6.6% [8, 12].

Thus, the use of anti-friction TMSBs instead of plain friction TMSBs is a priority direction for locomotive development for newly constructed locomotives and for those in operation.

The solution of the set tasks for introduction of WMB with anti-friction bearings demanded the search for alternative variants and new technical solutions. Therefore, the specialists of «Scientific and Technical Center «Pryvod» LLC and PJSC «Scientific-Production Enterprise «Smelyansky Electromechanical Plant» have been developed and patented in the State Intellectual Property Service of Ukraine (patent for utility model No. 84796 dated October 25, 2013) the project for modernization of WMB locomotive with anti-friction TMSB replacement.

Modernization of WMB consists of two stages:

- Modernization of traction electric motor with prolongation of service life for 15 years;
- Modernization of wheel set and the gear casing (if required).

In accordance with the technical specifications of TU U 30.2-38414897-004: 2014 «Modernization of wheel-motor blocks of locomotives including replacement of plain friction TMSB with the anti-friction TMSB», modernization of the traction motor is carried out during its overall repair. This includes the repair of the engine case, anchor and magnetic system with replacement of windings and isolation of the class of heat resistance not lower than «H», bearing units with the restoration of their sizes to drawings and the execution (if necessary) of improvements in accordance with the requirements of design documentation for modernization. Conducting of modernization can increase the TEM life for 15 years.

### Purpose

The purpose of the article is to determine the technical and economic efficiency of the modernization of locomotive WMB TMSB with anti-friction bearings based on LCC calculations.

### Methodology

At the present time in Ukraine there are several normative documents in the field of cost-effectiveness analysis of investments. The main ones are:

– Procedure and Criteria for Assessing the Economic Efficiency of Project (Investment) Proposals and Investment Projects, approved by the Cabinet of Ministers of Ukraine as of 18.07.2012, No. 684;

– Methodological Recommendations on Development of State Supported Investment Projects, approved by Order of the Ministry of Economic Development and Trade of Ukraine as of 13.11.2012, No. 1279;

– Methodological Recommendations on Assessment of Economic and Social Efficiency of State Target Program Implementation, approved by Order of the Ministry of Economy of Ukraine as of 24.06.2010, No. 742;

– Methodology of Conducting State Expertise of Investment Projects, approved by Order of the Ministry of Economic Development and Trade of Ukraine as of 13.03.2013, No. 243;

– Methodological Recommendations on Development of Business Plan of Enterprises, approved by Order of the Ministry of Economy of Ukraine as of 06.09.2006, No. 290;

– Methodology for Determining the Cost-effectiveness of Research and Development and their Implementation in Production, approved by Order of the Ministry of Economy and European Integration and the Ministry of Finance of Ukraine as of 26.09.2001, No. 218/446.

The Procedure and Criteria for Assessing the Economic Efficiency of Project (Investment) Proposals and Investment Projects, approved by the Cabinet of Ministers of Ukraine as of 18.07.2012 No. 684 stipulate that the assessment of the economic efficiency of an investment project is carried out according to the following criteria: net present value, internal rate of return, discounted payback period and profitability index. Herewith, the conclusion is positive about the effectiveness of the investment project, if the net present value is positive, the internal rate of return is greater than the standard discount rate, and the profitability index exceeds 1. The use of these criteria of economic efficiency fully corresponds to modern principles, theoretical and methodological approaches

and world practice regarding assessment of investment efficiency. However, the mentioned document does not contain specific methodological approaches, but suggests that the calculation of the criteria for the economic efficiency of an investment proposal, an investment project is carried out in the light of the Methodological Recommendations on Development of State Supported Investment Projects, approved by the Ministry of Economic Development and Trade.

Methodological Recommendations on Development of State Supported Investment Projects, approved by Order of the Ministry of Economic Development and Trade of Ukraine as of 13.11.2012, No. 1279 contains (paragraph 2.8) the methodology for determining the above mentioned investment efficiency indices. At the same time, the methodological recommendations do not explain the issue of considering risks when assessing the effectiveness of the project. It is intended to provide in the project a separate section on information on project risks, precautionary measures and risk insurance in cases stipulated by law (paragraph 2.10). Herewith, only a qualitative characteristic of risks is foreseen. That is, the above Methodological Recommendations do not contain quantitative methods for assessing investment risks and their accounting procedure when assessing the cost-effectiveness of an investment project.

Methodological Recommendations on Assessment of Economic and Social Efficiency of State Target Program Implementation, approved by Order of the Ministry of Economy of Ukraine as of 24.06.2010, No. 742, among other things, contain an algorithm for calculating the four key indices of economic efficiency, which coincides with the methods presented in the above Methodical Recommendations on Development of Investment Project. It also proposes the use of several specific indices for innovative projects: value added, ratio of investments (private and public), commercialization coefficient and new product sales coefficient. In addition, the Methodical recommendations under consideration include methods for assessing the synergistic economic effect of program interaction, which allow assessing the economic effectiveness of the program as a system of interconnected projects, that is to move from the assessment of individual investment projects to the assessment of the effectiveness of their integrated implementation. The synergistic effect of program

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interaction includes the effects of program centralization, concentration, specialization, cooperation and replication of intermediate and final results. The mentioned Methodological Recommendations contain methodological approaches to the determination of each of these effects. However, these Methodological Recommendations do not also contain the methodological approaches to risk assessment in determining the cost-effectiveness of investment projects and programs.

Methodological Recommendations on Development of Business Plan of Enterprises, approved by Order of the Ministry of Economy of Ukraine as of 06.09.2006, No. 290 contain methodological approaches for forecasting cash flows from the activity of the enterprise and determination of economic investment efficiency indices, which, in general, coincide with the Methodological Recommendations on Development of Investment Project, are more detailed. The Methodological Recommendations under consideration also do not include approaches to quantitative investment risk. However, based on the analysis of paragraph 2.1.10.3 of the Methodological Recommendations, one can conclude that the main way of taking into account the risks in assessing the economic efficiency of investments is to increase the discount rate by the risk premium, since it is determined that «discount rate ( $r$ ) is the rate of profit, that investors usually receive from investments of similar content and degree of risk».

Methodology for Determining the Cost-effectiveness of Research and Development and their Implementation in Production, approved by Order of the Ministry of Economy and European Integration and the Ministry of Finance of Ukraine as of 26.09.2001, No. 218/446 contains approaches to the definition of key indices of economic efficiency of projects. At the same time there are differences with the previously considered normative acts in determining the «profitability index». So in these recommendations it is defined as the ratio of net discounted income to the discounted investment value, and in all other regulatory acts – as the ratio of the present value of the results (net cash inflow) to the present value of investment outlay. As the Procedure and Criteria for Assessing the Economic Efficiency of Project (Investment) Proposals and Investment Projects, approved by the Cabinet of Ministers of Ukraine as of 18.07.2012 No. 684 determines the efficiency criterion as the profitability

index higher than 1, more correct definition of this index is given in the Methodological Recommendations on Development of State Supported Investment Projects, approved by Order of the Ministry of Economic Development and Trade of Ukraine as of 13.11.2012, No. 1279. However, the Methodology for Determining the Cost-effectiveness of Research and Development and their Implementation in Production contains certain elements of methodological approaches to risk assessment when measuring efficiency. Thus, the paragraphs 3.20 and 3.21 of the Methodology stipulate that mid-term and long-term R & D projects concerning the timing of their implementation need to take into account the uncertainty and risk factor. The following methods can be used to take into account the uncertainty and risk factor: verification of project sustainability, adjustment of project parameters, formal description of uncertainty. The project sustainability is determined by the break-even point. Correction of project parameters is based on refinement of the initial technical and economic task, including the terms of the project due to delays in financing its stages, procedural violations in the implementation of innovations, violation of terms of feedstock supply and other complications. In all cases of such violations the resulting losses are added to the project cost structure. The paragraph 3.22 (formula 3.16) of the Methodology stipulates the application of a capital asset valuation model to determine the discount rate allowing for risk.

Thus, domestic regulatory acts in the field of cost-effectiveness analysis of innovation and investment projects reflect a certain methodical toolkit on the structure of forecast cash flows, the definition of their components, the calculation of the main indicators of economic efficiency of investment, taking into account the factor of time, which in general corresponds to the modern theoretical foundations of cost-effectiveness analysis and project analysis [1, 3, 4, 7, 10, 13, 15].

A cost-effectiveness analysis of an innovation and investment project is carried out at such stages.

- I. Determination of project life cycle.
- II. Forecast of cash flows by the base project scenario.
- III. Quantitative assessment of the risk level of the project.
- IV. Determination of discount rates for the base investment project scenario based on the rate of return and risk level.

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V. Determination of indices of effectiveness by the base scenario and discount rate allowing for risk premium.

The net present value of the innovation and investment project is determined by the formula:

$$NPV = \sum_{t=0}^T \frac{E_t}{(1+R)^t} - \sum_{t=0}^T \frac{I_t}{(1+R)^t}, \quad (1)$$

where  $NPV$  – net present value;  $R$  – discount rate;  $T$  – project life cycle;  $E_t$  – the result (economic effect) of the project in the  $t$ -th period;  $I_t$  – investment costs of the project in  $t$ -th period.

The criterion for project efficiency is the positive value of  $NPV$ .

When forecasting the results and costs of a project in this work we use the concept of base (fixed for a certain date) prices. Therefore, in the project under consideration, the forecasted economic effect varies little over the years of the investment life cycle and can be taken at the average annual level. Investment costs of the project arise only in the beginning of the investment life cycle and equal to the locomotive modernization cost. Therefore, the formula for determining the net present value of a project can be presented as:

$$NPV = \bar{E} \cdot \frac{1-(1+R)^{-T}}{R} - I, \quad (2)$$

where  $\bar{E}$  – annual economic effect of locomotive modernization;  $I$  – locomotive modernization cost;  $T$  – useful life of the locomotive.

The project internal rate of return is defined as the discount rate, according to which the net present value of the project is zero. It is established by solving the equation:

$$\bar{E} \cdot \frac{1-(1+IRR)^{-T}}{IRR} - I = 0, \quad (3)$$

where  $IRR$  is the internal rate of return.

The project effectiveness criterion is the excess of the internal rate of return over the discount rate.

The project profitability index (PI) is determined by the formula:

$$PI = \frac{\bar{E} \cdot \frac{1-(1+IRR)^{-T}}{IRR}}{I}. \quad (4)$$

The project effectiveness criterion is the value of the profitability index, which is greater than or equal to one.

The discounted payback period of the project investments is defined as the period from the start of the life project cycle to the moment after which the accumulated net present value of the portfolio becomes and continues to remain positive. The effectiveness criterion is the magnitude of the dynamic payback term, which is less than or equal to the duration of the life portfolio cycle.

Under the basic prices when forecasting cash flows we exclude the inflation component from the composition of the discount rate by the formula:

$$R = \frac{R_n - i}{1 + i}, \quad (5)$$

where  $R$  – real discount rate;  $R_n$  – nominal rate discount;  $i$  – forecasted inflation rate.

The cost-effectiveness analysis of locomotive modernization is carried out on the basis of comparison of costs with the results arising from the modernization during the life cycle of the locomotive.

The life cycle is taken equal to the normative lifetime of the diesel locomotive. As investment costs we considered the costs associated with the higher cost of the wheel-motor block (WMB) with anti-friction TMSB in comparison with the WMB with plain friction TMSB. The results are saving operating costs, which are provided by the replacement of plain friction TMSB with anti-friction TMSB. The mentioned costs are taken into account in locomotive modernization cost.

The average annual economic effect of locomotive modernization consists of operating costs saving associated with the locomotive operation, and includes:

- oil cost savings;
- cost savings for repair and maintenance of diesel locomotive wheel-motor blocks, including the change of TMSB brass;
- fuel consumption saving for hauling operations.

The oil cost savings are determined based on the amount of oil changes and refilling to the plain friction and anti-friction TMSB during repairs, the oil cost for changes (refilling) during maintenance and the price of the oil of the corresponding type.

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The cost savings for repairing and servicing diesel locomotive wheel-motor blocks are determined on the basis of the complexity of the work involved, the tariff rates of the workers and the cost of the brasses used for changes.

The fuel consumption saving for hauling operations is determined on the basis of increasing the coefficient of useful efficiency of gear transmission with anti-friction TMSB, in comparison with plain friction TMSB.

The starting data for the cost-effectiveness analysis of diesel locomotive modernization are the operating norms of operation, maintenance and repair of locomotives of a particular series, data of the developer of modernization, statistical data of PJSC «Ukrzaliznytsia», State Statistics Service of Ukraine, National Bank of Ukraine and results of own researches of the executors of this work. Output data for cost-effectiveness analysis of modernization of M62 diesel locomotive are shown in Table 1, 2.

Table 1

**Output data for cost-effectiveness analysis, differing in variants**

Index	Unit of measure	Value for the locomotive with			
		Plain friction TMSB	Information source	Anti-friction TMSB	Information source
Oil used in TMSB	–	axial oil of «L», «Z» grades (GOST 610-72)	data of PJSC «UZ»	«Agrinol» oil	data of a developer
Frequency of full oil filling of TMSB	–	during repairs with disassembly of WMB, in the case of brass change, during seasonal oil change	[4]	CR-3, OR-1, OR-2	data of a developer
Frequency of TMSB oil refilling	–	M-2, M-3	[4]	CR-2	data of a developer
Amount of oil consumed when completely changed	l/lubr. point	12	data of PJSC «UZ»	1.5	data of a developer
Amount of oil consumed when refilled	l/lubr. point	0.4	data of PJSC «UZ»	0.15	data of a developer
Oil price, ex VAT	UAH/l	12.5	prozorro.gov.ua	51.82	data of a developer

Table 2

**Output data for cost-effectiveness analysis, similar in variants**

Index	Unit of measure	Value
Number of lubrication points	un./sect.	12
Normative inter-repair periods:		
– maintenance M-2	hours	72
– maintenance M-3	ths. km	10
– current repairs CR-1	ths. km	50
– current repairs CR-2	ths. km	95
– current repairs CR-3	ths. km	195
– overall repair OR-1	ths. km	780
– overall repair OR-2	ths. km	1 560

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Continuation of a table 2

Index	Unit of measure	Value
Number of lubrication points	un./sect.	12
Average rate of shed percentage of defective diesel locomotives	%	8
Normative term of operation of diesel locomotive	years	20
Hourly rate of rolling stock repair mechanic, taking into account all surcharges:		
– 3-rd category	UAH/year	33.47
– 5-th category	UAH/year	42.92
The rate of unified social tax	%	22
Average cost of the package of TMSB brasses, ex VAT	UAH/TMSB	50 000
Actual specific consumption of diesel fuel in freight traffic for M62 series locomotive	kg/10 000 t-km br.	34
Hourly fuel consumption at idle speed	kg/year	25
Average weight of freight train with M62 series locomotive	ton	3 781.82
Average mileage of M62 series diesel locomotives	km	416
Cost of diesel fuel, ex VAT	UAH/t	22 059
Increase in the efficiency coefficient of gear with anti-friction TMSB, in comparison with plain friction TMSB	times	1.055
Cost of modernization of the wheel-motor block under anti-friction TMSB, ex VAT	ths. UAH	357.6
Average technical speed	km/year	45.6

### Findings

To determine the flow of lubricants to lubricate the TMSB, the number of repairs and maintenance for the life cycle of the diesel locomotive is determined in accordance with the repair cycle chart.

The assigned lifetime of the locomotive mileage is defined as a double life of the run prior to major repairs within OR-2, which is 3120 thousand km. Proceeding from the mileage resource of the M62 series locomotive and the standards of inter-repair runs, the normative quantity of repairs and maintenance of the locomotive for a life cycle is determined, which is:

- OR-2 – 1 repair;
- OR-1 – 2 repairs;
- CR-3 – 12 repairs;
- CR-2 – 17 repairs;
- CR-1 – 29 repairs;
- M-3 – 250 maintenances per cycle;
- M-2 – 112 maintenances per year.

When performing the overall, current repairs, as well as maintenance for the locomotives with

plain friction TMSB, during a seasonal oil change, its full replacement is carried out. In the course of maintenance, the plain friction TMSBs are refilled with oil [5]. The oil consumption for a complete change for the plain friction TMSB is:  $12 \cdot 12 = 144$  l for the locomotive section, for oil refilling:  $12 \cdot 0.4 = 4.8$  l for the locomotive section. Thus, the average annual oil consumption for plain friction TMSB reaches 1 322.4 l.

When performing the overall and current repairs for diesel locomotives with anti-friction TMSB within CR-3, a complete change of oil is carried out. When performing maintenance within M-2, the anti-friction TMSBs are refilled with oil. The oil consumption for a complete change for the anti-friction TMSB is:  $12 \cdot 1.5 = 18$  l for the locomotive section, for oil refilling:  $12 \cdot 0.15 = 1.8$  l for the locomotive section. Thus, the average annual oil consumption for the anti-friction TMSB reaches 15.93 litres.

Taking into account the loss of oil when pouring and refilling (10%), the average annual cost of lubricants is:

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– for locomotive with plain friction TMSB – 18 183 UAH;

– for locomotive with anti-friction TMSB – 908 UAH.

The cost savings for lubricants are:  $18\,183 - 908 = 17\,275$  UAH per year.

Costs for maintenance and repair of M62 locomotive WMB with plain friction and anti-friction TMSB include the costs associated with:

– remuneration of employees engaged in the maintenance and repair of WMB, the level of which is determined by the complexity and skill of repair personnel;

– cost of materials and spare parts for maintenance and repairs.

Labor costs are determined on the basis of the list of TMSB-related works performed during maintenance and repairs, the normative level of work and the value of the standard hour of the respective category. It takes into account the time factor for support needs 1.093 (for preparatory and final actions 3.5%, time for servicing the workplace 3.1%, time for rest and personal needs 2.7%, total – 9.3%).

The labor intensity of the anti-friction TMSB maintenance is adopted at the level of 25% of the corresponding value for the plain friction TMSB

due to simplification of the process of servicing the anti-friction TMSB.

The costs associated with remuneration are given in Table. 3

Table 3 shows that the average annual labor costs are: for the plain friction TMSB  $18\,1926/20 = 9\,096$  UAH, for the anti-friction TMSB  $19\,412/20 = 971$  UAH. Thus, the cost savings associated with remuneration are  $9\,096 - 971 = 8\,125$  UAH per year.

During the lifecycle of the M62 series locomotive, when performing overhaul repair, a complete change of the TMSB brasses is performed. During CR-3 current repairs 35% of brasses are changed. The cost of the package of TMSB brasses is 50 thousand UAH ex VAT. Thus, the average annual cost savings for spare parts is:

$$\frac{(50\,000 \cdot (1+2) + 50\,000 \cdot 12 \cdot 0.35) \cdot 12}{20} = 216\,000 \text{ UAH/year.}$$

In the middle conditions of operation, the M62 series diesel locomotive (incl. the idle time in repairs) per year carries out gross turnover in the amount of:

Table 3

**Calculation of expenses connected with remuneration of labour for work with TMSB during repairs and maintenance of M62 series diesel locomotive during the life cycle**

Type of repair, maintenance	Class of work	Hourly rate, UAH	Labour intensity with allowance for auxiliary time, man-hour		Number of maintenances, repairs	Non-worked time rate	Payroll fund, UAH		Unified social tax, UAH		Total expenses, UAH		
			Plain friction	Anti-friction			Plain friction	Anti-friction	Plain friction	Anti-friction	Plain friction	Anti-friction	
M-2	3	33.47	0.38	0	2240	1.1	31 339	0	6 895	0	38 234	0	
M-3	5	42.92	4.59	0	250	1.1	54 176	0	11 919	0	66 095	0	
CR-1	5	42.92	12.1	3.03	29	1.1	16 567	4 149	3 645	913	20 212	5 062	
CR-2	5	42.92	16.26	4.07	17	1.1	13 050	3 267	2 871	719	15 921	3 986	
CR-3	5	42.92	38.13	9.53	12	1.1	21 602	5 399	4 752	1 188	26 354	6 587	
OR	5	42.92	87.44	21.86	3	1.1	12 385	3 096	2 725	681	15 110	3 777	
Total per life cycle								149 119	15 911	32 807	3 501	181 926	19 412



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$$3781.82 \cdot 416 \cdot (1 - 0.08) \cdot 365 \cdot 10^{-6} = \\ = 528.3 \text{ mln. t-km br.}$$

Specific fuel consumption is 34 kg per 10000 ton-km br. Total fuel consumption per year reaches

$$\frac{528.3 \cdot 10^6 \cdot 34}{10000} \cdot 10^{-3} = 1796.22 \text{ tons.}$$

Average section speed reaches 45.6 km/h, then time in the movement of the diesel locomotive of the operating rolling stock is

$$\frac{416}{45.6} = 9.12 \text{ hours per day.}$$

The annual budget of idle time in «hot» condition of the M62 series locomotive reaches:

$$(24 - 9.12) \cdot 365 \cdot (1 - 0.08) = 4997 \text{ hours per year.}$$

Fuel consumption for idle time in «hot» condition reaches:

$$4997 \cdot 25 \cdot 10^{-3} = 124.9 \text{ tons.}$$

Fuel consumption of the M62 series locomotive in the train operation reaches:

$$1796.22 - 124.9 = 1671.32 \text{ tons.}$$

Since the gear ratio efficiency of the anti-friction TMSB is 1.055 times higher than that of the plain friction TMSB, fuel savings will average over the year

$$1671.32 - \frac{1671.32}{1.055} = 87.1 \text{ tons.}$$

At the cost of diesel fuel of 22059 UAH/ton, the annual saving in fuel consumption for hauling operation will be:

$$87.1 \cdot 22059 = 1921339 \text{ UAH per year.}$$

The overall average annual economic effect of modernizing the section of the M62 series locomotive reaches:

$$(17275 + 8125 + 216000 + 1921339) \cdot 10^{-3} = \\ = 2162.7 \text{ ths. UAH per year.}$$

Investment costs per M62 series locomotive section are defined as the product of the number of WMBs and the cost of upgrading one WMB and equal to:

$$6 \cdot 357.6 = 2145.6 \text{ ths. UAH ex VAT.}$$

The discount rate is determined using the model of capital asset valuation ( $\beta$ -method) as the cost of capital invested in the field of economic activity «Transport».

The risk factor  $\beta$  is defined as the ratio of the covariance of the return of the investigated investment asset and the capital market return.

As a measure of return on investment, the profitability of equity capital of large and medium-sized enterprises in Ukraine as a whole (capital market return ratio) and the sphere of economic activity of «Transport» (investment assets return ratio) are used. The net profit and equity figures are shown in the Table 4 [9].

According to Table 4, the covariance of profitability (55.7) and market profitability dispersion (155.4) were determined. Thus, the Betta coefficient for investments in the sphere of economic activity «Transport» reaches

$$\beta = \frac{55.7}{155.4} = 0.358.$$

As the base rate, we used the rate of return on investments with a minimum risk – the average interest rate on long-term deposits of economic entities in 2017 was 14.3%.

The yield of the stock market at the current time is defined as the average yield of the stock index UX (index of Ukrainian shares) per one year (from 15.11.2016 to 15.11.2017). The index at period beginning was 791.11, at period end – 1261.62 [9]. The average annual rate of income is

$$R_m = \frac{1261.62}{791.11} \cdot 100 - 100 = 59.47 \text{ \%}.$$

Thus, the nominal discount rate before taxation is

$$R = R_b + \beta \cdot (R_m - R_b) = \\ = 14.3 + 0.358 \cdot (59.47 - 14.3) = 30.5 \text{ \%}.$$

Table 4

## Determination of the return on equity

Year	Net financial result, mln. UAH		Average equity, mln. UAH		Equity at period end, mln. UAH		Return on equity, %	
	in Ukraine	transport	in Ukraine	transport	in Ukraine	transport	in Ukraine	transport
2016	13 324,4	6 622,533	1 790 507	727 082,3	1 806 908,5	729 340,6	0,74	0,91
2015	-373 516	-17 847,8	1 627 381	438 080,6	1 774 104,6	724 823,9	-22,95	-4,07
2014	-590 067	-22 591,6	1 715 516	165 346,2	1 480 658	151 337,3	-34,4	-13,66
2013	-22 839,7	-1 423,4	1 927 658	176 269,8	1 950 374,9	179 355,1	-1,18	-0,81
2012	35 067,3	3 127,7	1 745 612	179 525,3	1 904 940,2	173 184,5	2,01	1,74
2011	67 797,9	2 839,8	1 506 498	180 235,4	1 586 284,7	185 866	4,5	1,58
2010	13 906,1	1 348,7	1 348 125	169 027,3	1 426 711,6	174 604,7	1,03	0,8
2009	-37 131,1	4 889,5	1 201 571	155 846,4	1 269 537,7	163 449,8	-3,09	3,14
2008	-41 025,1	234,5	1 081 690	139 033,1	1 133 603,7	148 242,9	-3,79	0,17
2007	–	–	–	–	1 029 775,5	129 823,2	–	–

When forecasting the costs, the concept of base prices is used, so the real discount rate is used for discounting. The inflation rate is assumed to be 11% per year [9]. That is, the real discount rate reaches:

$$\frac{30.5 - 11}{1 + 0.11} = 17.6 \%$$

Thus, the main indices of the economic efficiency of modernization of the M62series locomotive are as follows:

– Net present value (formula (2))

$$NPV = 2162.7 \cdot \frac{1 - (1 + 0.176)^{-20}}{0.176} - 2145.6 = 9662 \text{ ths. UAH};$$

– Internal rate of return (3))

$$2162.7 \cdot \frac{1 - (1 + IRR)^{-20}}{IRR} - 2145.6 = 0;$$

$$IRR = 1.007;$$

– Profitability index (formula (4))

$$PI = \frac{2162.7 \cdot \frac{1 - (1 + 0.176)^{-20}}{0.176}}{2145.6} = 5.5 \text{ times};$$

– Static payback period is:

$$T_{pp} = \frac{2145.6}{2162.7} \cdot 12 = 11.9 \text{ months.}$$

The graph of accumulation of the net present value of the project is shown in Fig. 1

Originality and practical value

Taking into account the specifics of the type of locomotive work in freight traffic, we developed a method to determine the individual components of the average annual economic effect of modernization of the diesel locomotive WMB, which includes saving of oil costs, repairing and servicing the diesel locomotive WMB, as well as change of TVSB brass and saving fuel costs for traction.

The practical value of the work lies in the fact that on the basis of the above methodology and research results it is possible to determine the expediency of modernizing the locomotive taking into account the peculiarities of its operation.

Conclusions

It is clear from the calculations above that the net present value (*NPV*) of the project is 9662 thousand UAH, the internal rate of return (*IRR*) of the project is 100.7%, which exceeds the discount rate, the profitability index (*PI*) of the project is 5.5 times higher than 1. Schedule in Fig. 1 shows that the discount payback period of the project is 1.2

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years (14.4 months), which is considerably less than the life cycle of investments.

Thus, the main criteria testify that the considered innovative project on modernization of M62

series locomotive provides a high level of cost effectiveness.

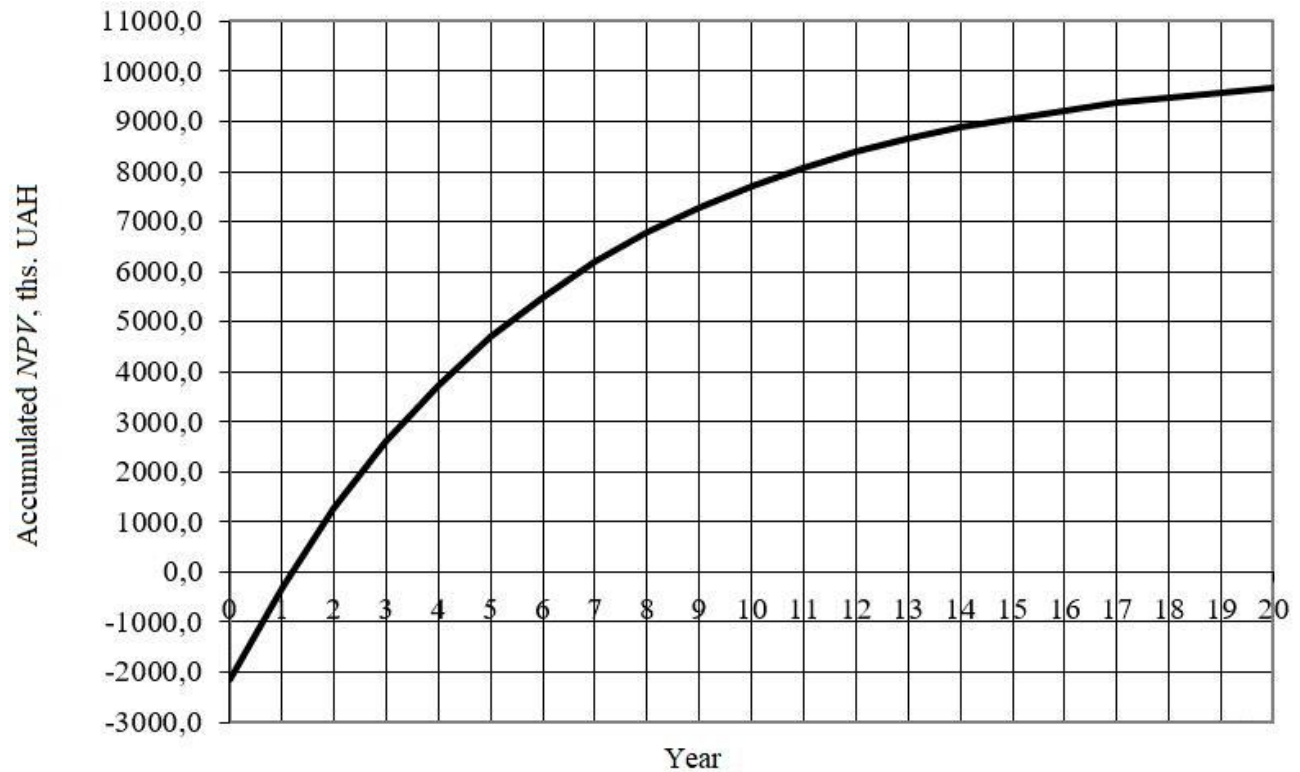


Fig. 1. Accumulation of net present value

At the same time, the value of the discounted investment payback period for modernization shows that it is expedient to conduct it if the remaining useful lifetime of the modernization object (M62 series diesel locomotive) is not less than 15 months.

The feasibility study is executed in the prices and standards of 2017 at the stage of development of the technical documentation for WMB modernization and should be clarified according to the results of their work in real operating conditions.

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## ЕФЕКТИВНІСТЬ МОДЕРНІЗАЦІЇ КОЛІСНО-МОТОРНИХ БЛОКІВ ТЕПЛОВОЗА З ВИКОРИСТАННЯМ МОТОРНО-ОСЬОВИХ ПІДШИПНИКІВ КОЧЕННЯ

**Мета.** Використання моторно-осьових підшипників (МОП) кочення замість моторно-осьових підшипників ковзання є пріоритетним напрямком розвитку локомотивобудування й експлуатації наявних локомотивів. Вирішення завдань щодо впровадження на локомотивах колісно-моторних блоків (КМБ) із підшипниками кочення потребує пошуку альтернативних варіантів і нових технічних рішень. Метою статті є визначення доцільності переобладнання колісно-моторного блока тепловоза на підшипники кочення шляхом розрахунку життєвого циклу (*LCC*). **Методика.** Порядок і критерії оцінки економічної ефективності проектних (інвестиційних) пропозицій та інвестиційних проектів, затверджені постановою Кабінету Міністрів України, передбачають, що оцінку економічної ефективності інвестиційного проекту здійснюють за такими критеріями: чиста приведена вартість, внутрішня норма дохідності, дисконтований період окупності й індекс прибутковості. Використання зазначених критеріїв економічної ефективності повністю відповідає сучасним принципам, теоретико-методичним підходам і світовій практиці оцінки ефективності інвестицій. У роботі оцінка техніко-економічної ефективності модернізації колісно-моторного блока

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тепловоза проведена на основі розрахунку й порівняння наступних критеріїв – чистої приведеної вартості (NPV) модернізації, внутрішньої норми доходу (IRR), індексу дохідності (PI) й дисконтного терміну окупності. **Результати.** Виконані розрахунки значень основних критеріїв свідчать, що інноваційний проект із модернізації тепловоза забезпечує високий рівень економічної ефективності. При цьому величина дисконтованого терміну окупності інвестицій у модернізацію передбачає, що її проведення є доцільним, якщо залишковий ресурс строку корисного використання модернізованого тепловоза серії М62 не менший за 15 місяців. **Наукова новизна.** З урахуванням особливостей виду роботи тепловоза під час руху в складі вантажного поїзда розроблена методика з визначення окремих складових середньорічного економічного ефекту від модернізації колісно-моторного блока тепловоза. До них належать економія витрат на мастило, на ремонт й обслуговування колісно-моторного блока тепловоза, у тому числі заміну вкладишів МОП, та економія витрат на паливе для тяги поїздів. **Практична значимість.** Результати роботи дозволяють визначити доцільність модернізації тепловозів з урахуванням особливостей та умов їх роботи, а також специфіки модернізації.

*Ключові слова:* модернізація тепловоза; колісно-моторний блок; техніко-економічна ефективність; підшипники качення; життєвий цикл

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## ЭФФЕКТИВНОСТЬ МОДЕРНИЗАЦИИ КОЛЕСНО-МОТОРНЫХ БЛОКОВ ТЕПЛОВОЗА С ПРИМЕНЕНИЕМ МОТОРНО-ОСЕВЫХ ПОДШИПНИКОВ КАЧЕНИЯ

**Цель.** Использование моторно-осевых подшипников (МОП) качения вместо моторно-осевых подшипников скольжения является приоритетным направлением развития локомотивостроения и эксплуатации имеющихся локомотивов. Решение задач по внедрению на локомотивах колесно-моторных блоков (КМБ) с подшипниками качения требует поиска альтернативных вариантов и новых технических решений. Целью статьи является определение целесообразности переоборудования колесно-моторного блока тепловоза на подшипники качения путем расчета жизненного цикла (LCC). **Методика.** Порядок и критерии оценки экономической эффективности проектных (инвестиционных) предложений и инвестиционных проектов, утвержденные постановлением Кабинета Министров Украины, предполагают, что оценка экономической эффективности инвестиционного проекта осуществляется по следующим критериям: чистая приведенная стоимость, внутренняя норма доходности, дисконтированный период окупаемости и индекс доходности. Использование указанных критериев экономической эффективности полностью соответствует современным принципам, теоретико-методическим подходам и мировой практике оценки эффективности инвестиций. В работе оценка технико-экономической эффективности модернизации колесно-моторного блока тепловоза проведена на основе расчета и сравнения следующих критериев – чистой приведенной стоимости (NPV) модернизации, внутренней нормы дохода (IRR), индекса доходности (PI) и дисконтного срока окупаемости. **Результаты.** Выполненные расчеты значений основных критериев свидетельствуют, что инновационный проект по модернизации тепловоза обеспечивает высокий уровень экономической эффективности. При этом величина дисконтированного срока окупаемости инвестиций в модернизацию предусматривает, что ее проведение целесообразно, если остаточный ресурс срока полезного использования модернизированного тепловоза серии М62 не менее 15 месяцев. **Научная новизна.** С учетом особенностей вида работы тепловоза во время движения в составе грузового поезда разработана методика по определению отдельных составляющих среднегодового экономического эффекта от модернизации колесно-моторного блока тепловоза. К ним относятся экономия расходов на смазку, на ремонт и обслуживание колесно-моторного

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блока тепловоза, в том числе замену вкладышей МОТ, и экономия затрат на топливо для тяги поездов. **Практическая значимость.** Результаты работы позволяют определить целесообразность модернизации тепловозов с учетом особенностей и условий их работы, а также специфики модернизации.

*Ключевые слова:* модернизация тепловоза; колесно-моторный блок; технико-экономическая эффективность; подшипники качения; жизненный цикл

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