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Mathematical Modeling of the Economic Effectiveness of Repurposed Automotive Engine Swap Kits for Diesel Generator Units

Aimukhanov D.S. [1], Mehtiev A.D. [1], Wargula L.[2], Sembaev N.S.[3], Aimukhanov S.M.[3]
[1,2] Abylkas Saginov Karaganda Technical University», Karaganda, Kazakhstan
[2] Poznan Polytechnic University, Poland, Poznań
[3] Toraigyrov University, Pavlodar, Kazakhstan

Abstract. The article employs an integrated scientific research method, including systems, kinematic, and comparative analysis, as well as techno-economic modeling. A methodology is proposed for evaluating the economic efficiency of utilizing automotive «swap kits» (complete engine assemblies including auxiliary systems and attachments) and manual transmissions for subsequent operation in stationary machinery drives, using diesel generators as a primary example. An efficiency criterion is introduced based on a comparison of the levelized cost per engine hour, fuel consumption, and total lifecycle savings. The role of gearboxes in the drive design is substantiated. The developed mathematical model, which accounts for capital expenditures, differences in specific fuel consumption, and residual engine life, enables the justification of techno-economic advantages and efficiency conditions. The results of the study are recommended as an engineering methodology for the rapid assessment of swap project efficiency in stationary machinery drive systems.

Keywords: mathematical model, swap kit, diesel generator, residual engine life, specific fuel consumption, economic efficiency, manual transmission gear.

Introduction

Currently, in the territory of the EAEU countries, the practice of upgrading commercial passenger and freight vehicles – in particular, the Gazelle, Ford, and Mercedes-Benz families – has seen increasing adoption of a method whereby the factory engine and associated components are replaced with complete power units that are used but exhibit high reliability and remaining service life. Units from brands such as Toyota, Mercedes-Benz, and Nissan, which are widely available and known for their reliability on the secondary market, are used as donors. Such kits are commonly referred to as «swap kits» [1].

The accumulated experience with swap kits in road transport opens prospects for their use in stationary machines, for example, as drives for diesel generators.

The alternative is the use of «swap kits» – power units removed from decommissioned vehicles but retaining significant remaining service life. Restoring the operability of stationary machines that have exhausted their service life by this method represents a promising direction for resource conservation. The practice of repurposing (converting) automotive internal combustion engines (ICEs) for use as part of stationary equipment creates favorable conditions for reducing vehicle recycling levels and achieving substantial material savings [2-4].

The economic feasibility of replacing standard industrial drives with automotive equivalents (“swap kits”) is determined by the following factors:

- Component cost. The expenses for acquiring components for repurposing a stationary machine drive are 3-5 times lower than the cost of a new industrial engine of equivalent power. A price analysis shows that the cost of a new 100 kW industrial diesel engine ranges from €8,000 to €12,000. At the same time, the cost of a contract (used but operational) automotive engine with comparable parameters and confirmed remaining service life varies between €1,500 and €2,500 [5];
- Logistics and availability. A significant reduction in transportation and logistics costs is achieved due to the well-developed network of vehicle dismantling enterprises (auto recyclers) and the wide availability of spare parts on the secondary market. This minimizes the time required to locate and deliver the necessary units [1]. The broad standardization and prevalence of service and repair facilities for automotive engines ensure high availability of both new and used spare parts, simplifying subsequent maintenance;
- Reduced downtime. The use of localized and easily accessible automotive units makes it possible to drastically shorten the time required to restore stationary machines. While waiting for delivery of a new industrial engine can take 3 to 6 months, the acquisition, delivery, and installation of an automotive equivalent typically takes 1 to 2 weeks, which is critical for reducing forced equipment downtime [1];
- Restoration cost. A comparative cost analysis demonstrates that the cost of repurposing and installing an automotive engine is 40–60% lower than the cost of overhauling a failed industrial engine. This effect is achieved due to the lower price of the original donor unit and the lower labor intensity of preparatory work [5-7];
- Utilization of remaining service life. Conversion enables the effective transfer of unused remaining service life of components from transport operating conditions to stationary operation. As noted in the technical literature [10], after 150-250 thousand km of mileage, the mechanical parts of an automotive engine retain up to 70-80% of their original

service life. In the gentle operating mode of a stationary installation (e.g., a standby generator), this potential can be realized over many years, effectively extending the product's life cycle [8];

– Application area. The operation of stationary machines restored by installing automotive ICEs becomes particularly relevant in hard-to-reach and less developed regions. Such units are optimal for use as temporary sources of mechanical energy or electric power generation during peak load periods, seasonal work, emergency power outages, and in road construction. Their low cost and rapid installation make them an ideal solution for local tasks where the use of expensive industrial equipment is economically unjustified;

Restoration by repairing or replacing the standard engines of stationary machines, such as diesel generators [9], often requires significant capital investment. The alternative is the use of «swap kits» – power units removed from decommissioned vehicles but retaining substantial remaining service life. This approach is being actively developed in the modernization of commercial vehicles.

The presence of a manual transmission (MT) or robotic transmission as part of such a kit makes it possible to optimize the internal combustion engine's operating mode with respect to the rotational speed of the loaded actuator shaft, bringing the engine into the zone of minimum specific fuel consumption. The aim of this work was to develop a mathematical model enabling a quantitative assessment of the feasibility of such an approach.

1. Materials and Methods

Within the framework of this study, a comprehensive methodological apparatus integrating engineering, technical, and economic approaches was applied to assess the feasibility of using automotive swap kits in stationary machine drives. The main research methods include:

1. Method of technical-economic modeling and system analysis. The methodological approach of this work is system analysis of the resource and cost aspects of the life cycle of power units. On this basis, a rigorous formalization of the cost structure was performed: capital investments (acquisition, adaptation, installation) and operating expenses (fuel consumption) were differentiated and structured for two competing scenarios – implementation of a swap project versus conventional overhaul (or replacement) of the standard industrial engine. This made it possible to develop a comprehensive technical-economic model describing system behavior under real operating conditions;
2. Method of comparative economic efficiency and cost normalization. To ensure objective comparability of power units with significantly different useful lifetimes (remaining service life), the method of normalizing costs to a common baseline – the cost per operating hour – was applied. This step allowed correct comparison of heterogeneous capital and fuel costs, eliminating distortions arising from differences in initial cost and projected durability of the components;
3. Analytical mathematical modeling. Based on the identified economic indicators, a system of mathematical equations was developed. The outcome of the analytical synthesis was the derivation of a final functional relationship serving as the main payback criterion. The developed model (Equation 23) mathematically relates three key independent variables: the difference in capital investments, the delta of specific fuel consumption, and the available remaining service life of the donor engine [11, 12];
4. Kinematic analysis and optimization of operating modes for systems with discrete states. To substantiate the achievement of fuel efficiency, an approach accounting for the influence of gear ratios of the mechanical transmission was applied. The presence of a manual transmission (MT) is considered as a tool for matching the external speed characteristic of the automotive engine with the required synchronous speed of the generator. It was demonstrated by calculation that selecting the optimal gear allows the power unit to be purposefully operated in the zone of maximum torque and minimum specific fuel consumption;
5. Computational experiment and parametric visualization. To verify the developed analytical model and determine the domains of economic feasibility, a computational experiment was implemented using programming methods (Python). The numerical solution of the obtained mathematical relationships enabled the construction of contour plots and clear visualization of the multidimensional parameter space. This ensured precise determination of the break-even boundary and identification of zones generating net savings as a function of variable operating parameters.

Initial hypothesis is the assumption is that lower capital costs due to the use of a recycled swap kit, together with improved fuel efficiency through selection of the MT gear ratio, can compensate for the lower remaining service life of such a unit compared to a standard overhauled engine.

The study was performed in the following sequence:

– capital and fuel components were identified for the two compared options – the swap project and the alternative (overhaul / new engine);

– costs were normalized to a common indicator: the cost per operating hour was introduced, allowing correct comparison of options with different projected service lives (L_{rem} и L_{alt});

– efficiency criteria were developed: the total net savings (TS) over the entire service period of the swap unit is calculated as the difference between the normalized costs of the alternative and the project, multiplied by the remaining service life;

– based on the initial data of the experimental sample and using linear programming together with the scientific computing libraries NumPy and Matplotlib, a functional relationship was constructed to solve the mathematical model.

The proposed approach made it possible to quantitatively evaluate the influence of three key factors (capital costs, difference in specific fuel consumption, remaining service life) on the overall efficiency. The development of a mathematical model is justified because without formalized relationships it is impossible to reliably compare options with heterogeneous cost structures and service lives, nor to account for the nonlinear nature of specific fuel consumption [14] as a function of crankshaft rotational speed. The outcome of applying the integrated method is Equation (23), which can be used as an engineering technique for rapid assessment of swap projects.

2. Results and discussion

Equations of capital costs and fuel efficiency.

The economic efficiency of manufacturing a drive based on a swap kit is determined by comparison with the alternative (overhaul of the standard engine or purchase of a new one). The main criterion is the net savings over the projected operating period.

Let us represent the capital costs for the two options as follows [2, 15]:

– Costs for implementing the swap project:

$$I_{swap} = C_{swap.eng} + C_{adapt} + C_{gen} + C_{frame} + C_{other}, \text{ (m.u.)} \quad (1)$$

– Costs for the alternative option (overhaul of the standard engine):

$$I_{alt} = C_{repair}\ (C_{new}), \text{ (m.u.)} \quad (2)$$

where C_{swap} – cost of the swap kit (engine with MT and all auxiliary systems);

C_{adapt} – costs for adapting the engine, clutch, MT, and connecting the MT – alternator assembly;

C_{gen} – cost of repairing or restoring the alternator, if required (or the cost of a new alternator for manufacturing a stationary machine);

C_{frame} – cost of manufacturing the frame and mountings;

C_{other} – other costs (repurposing of engine auxiliary systems, calibration of the ECU, instrument panel, wiring, fuel system piping);

C_{repair} – cost of overhauling the standard engine;

C_{new} – cost of a new standard equivalent engine;

I_{swap} – total costs for manufacturing a diesel generator based on a swap kit, monetary units;

I_{alt} – costs for the alternative solution (overhaul or a new standard engine), monetary units.

To ensure a valid comparison, both options must be normalized to a common output power. Considering that the required power at the output shaft of the swap engine $N_{eng.req}$ must account for a power reserve of at least 15%, the maximum load power N_{req} and the generator efficiency η_{gen}, we obtain the following expression:

$$N_{eng.req} = \frac{1{,}15 \times N_{req}}{\eta_{gen}}, \quad (3)$$

where $N_{eng.req}$ – Required engine power including generator efficiency and safety margin (kW);

N_{req} – Required electrical power at the generator output (kW) at $N_{req} = N_{gen} \times \eta_{gen}$;

N_{gen} – Rated output power of the generator (kW);

η_{gen} – generator efficiency (typically 0,85 – 0,95).

The derived relationship allows for the use of either the maximum load power or the initial rated generator power in the calculations. The expressions for determining the theoretical volumetric fuel consumption were established in [3] by Kolchin A.L. and Demidov V.P. The volumetric flow rate for a swap engine equipped with a manual transmission is defined as follows:

$$V_{swap} = \frac{g_{swap} \times N_{eng.req}}{1000 \times \rho_{fuel}}, \text{ (l/h)} \quad (4)$$

For the standard engine:

$$V_{alt} = \frac{g_{alt} \times N_{n.gen}}{1000 \times \rho_{fuel}}, \text{ (l/h)} \quad (5)$$

where V_{alt} – volumetric fuel consumption of the standard engine (l/h);

V_{swap} – volumetric fuel consumption of the swap engine at the optimal MT gear (if any) (l/h);

g_{alt} – brake specific fuel consumption (BSFC) of the standard engine at power $N_{n.gen}$ (g/kWh);

g_{swap} – brake specific fuel consumption (BSFC) of the swap engine (with or without MT) at the required power (g/kWh);

$N_{n.gen}$ – rated power of the stock engine at the generator operating speed n_{gen}.

MT efficiency $\eta_{swap.gear}$ is not taken into account, $\eta_{swap.gear}$ =1 in the calculation due to its negligible value.

The rotational speed of the generator rotor (n_{gen}) for an industrial frequency of 50 Hz is typically 1500 or 3000 rpm. The presence of an MT makes it possible to vary the rotational speed of the engine crankshaft (n_{eng}) at a fixed n_{gen}:

$$n_{swap} = n_{gen} \times i_{gear} \quad (6)$$

By selecting the gear ratio i_{gear}, we can control the engine torque reserve M_{swap}. For the required power $N_{eng.req}$, the following relation holds:

$$N_{eng.req} = \frac{M_{swap} \times n_{swap}}{9550} \quad (7)$$

Selecting the optimal gear allows the engine to be loaded in the high – torque zone, which corresponds to minimum specific fuel consumption $g_{swap} = f\,(M_{swap}, n_{swap})$ [13].

In the calculations, it is assumed that the efficiency η_{gear} of a two – shaft or three – shaft MT is close to unity and is neglected, since any possible power loss during downshifting is compensated by an increase in torque.

In the operating mode with an MT, for a given required power $N_{eng.req}$ and a fixed generator speed n_{gen}, a gear ratio i_{gear} is selected to achieve a speed n_{swap} at which the torque M_{swap} will be greater than the torque required by the generator. In this zone, the specific fuel consumption g_{swap} will be minimal for the power $N_{eng.req}$.

The method for determining the theoretical specific, mass (volumetric) fuel consumption of an engine equipped with a manual transmission is based on the classic work by A.I. Kolchin and V.P. Demidov, «Calculation of Automotive and Tractor Engines» [3]. Their approach is particularly valuable because it allows for the analytical calculation of engine performance indicators in the absence of a complete BSFC map (efficiency map). Given the nominal data from the technical specifications $N_{eng.req}$ and g_{swap}, the calculations were performed using Leiderman's formula [2, 3].

As the reference drive for the swap project, a 4D68T engine with a VAZ-2107 5-speed MT was adopted. Based on known methods for determining operational characteristics and reference data, the specific fuel consumption at the MT gears is determined taking into account the constant rotational speed of the output shaft synchronized with the stationary machine (diesel generator).

Based on the calculation results required for the preliminary selection of an engine with MT for use as a diesel generator, the specific fuel consumption at various gears is determined (Fig. 1):

– On the 2nd gear (i_{gear} = 2,1) – operation is possible but not efficient. The engine rotates at 3150 rpm, which increases wear, noise, and specific fuel consumption (241 g/kWh).

– On the 3rd gear (i_{gear} = 1,36) – the most efficient option. When using this gear, to rotate the generator shaft at 1500 rpm, the 4D68T engine must be accelerated to 2040 rpm. At this speed, the 4D68T operates at its peak fuel efficiency (224 g/kWh), which is better than the nameplate data of the D-246.1 (226 g/kWh).

– On the 4th gear (i_{gear} = 1,0). When operating in direct drive, the engine will run at 1500 rpm. At low speeds, the 4D68T turbodiesel does not develop sufficient turbocharger pressure or torque, resulting in an increase in specific fuel consumption to 248 g/kWh. This is 10% worse than that of the D-246.1.

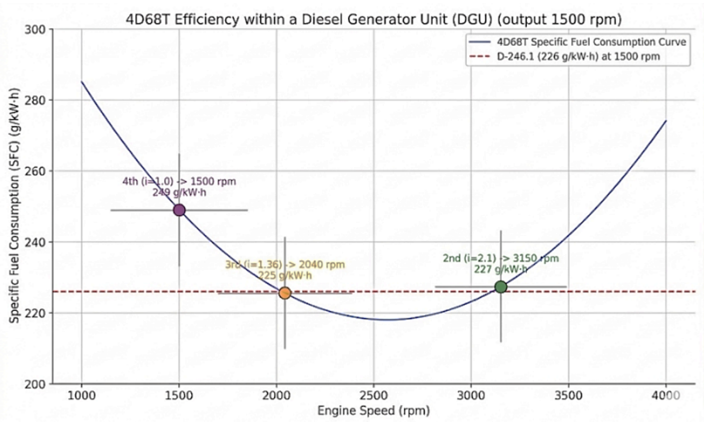

Fig. 1 – Specific fuel consumption curves for various gears of the swap kit (4D68T engine with VAZ-2107 5-speed MT) and for the standard D-246.1 engine with direct drive

The region between the 2nd and 3rd gears, situated below the red dashed reference line of the D-246.1, represents the theoretical reduction in specific fuel consumption (SFC).

Consequently, the aforementioned methodology enables the selection of an engine-MT (manual transmission) combination with gear ratios (i_{gear}) optimized for the swap project. This approach ensures that the engine’s crankshaft speed is minimized while still delivering the required torque (M_{swap}). This effectively shifts the engine's operating point into a zone characterized by high torque and low specific fuel consumption.

To evaluate the fuel efficiency of the swap project relative to the stock engine, the total fuel savings can be calculated for the projected remaining service life (L_{rem}) of the replacement engine [16].

Annual fuel savings ($S_{fuel.annual}$, monetary units/year):

$$S_{fuel.annual} = (V_{alt} - V_{swap}) \times T_{op} \times P_{fuel} \tag{8}$$

Substituting the fuel consumption formulas:

$$S_{fuel.annual} = \frac{((g_{alt} \times N_{n.gen}) - (g_{swap} \times N_{eng.req})) \times T_{op} \times P_{fuel}}{1000 \times \rho_{fuel}} \tag{9}$$

Total fuel savings over the entire remaining engine service life (Total Fuel Saving, monetary units):

$$S_{fuel.total} = \frac{(g_{alt} \times N_{n.gen} - g_{swap} \times N_{eng.req}) \times L_{rem} \times P_{fuel}}{1000 \times \rho_{fuel}} \tag{10}$$

where:

L_{rem} is the projected remaining service life of the swap engine (in operating hours);

T_{op} is the average annual operating time (hours/year), assuming $T_{op} = L_{rem} / n$ years;

L_{alt} is the projected service life of the stock engine (in operating hours) following an overhaul or major rebuild;

P_{fuel} is the diesel fuel price (monetary units per liter);

ρ_{fuel} is the diesel fuel density (typically assumed to be ~0,84 kg/L);

$S_{fuel.annual}$ is the annual fuel cost savings.

Normalizing costs to a single indicator. To compare options with different service lives, it is necessary to normalize costs per operating hour, accounting for both capital expenditures (CAPEX) and fuel expenses.

The normalized hourly cost for the swap unit ($C_{swap.hourly}$) is defined as follows:

$$C_{swap.hourly} = \frac{I_{swap}}{L_{rem}} + V_{swap} \times P_{fuel} \tag{11}$$

or

$$C_{swap.hourly} = \frac{I_{swap}}{L_{rem}} + \frac{g_{swap} \times N_{eng.req} \times P_{fuel}}{1000 \times \rho_{fuel}} \tag{12}$$

where I_{swap} / L_{rem} is the hourly depreciation of the fabrication (swap) cost;

$V_{swap} \times P_{fuel}$ is the fuel cost per operating hour;

$g_{swap} \times N_{eng.req} \times P_{fuel} / 1000 \times \rho_{fuel}$ is the fuel cost per operating hour, based on the reference specific fuel consumption (SFC) at a given swap engine power output.

The levelized hourly cost for the stock engine $C_{alt.hourly}$ with a projected post-overhaul service life L_{alt} is:

$$C_{alt.houtly} = \frac{I_{alt}}{L_{alt}} + V_{alt} \times P_{fuel} \tag{13}$$

or

$$C_{alt.hourly} = \frac{I_{alt}}{L_{alt}} + \frac{g_{alt} \times N_{n.gen} \times P_{fuel}}{1000 \times \rho_{fuel}} \tag{14}$$

A project is considered absolutely cost-effective if the hourly operating cost of the swap powertrain is lower than that of the alternative:

$$C_{swap.hourly} \leq C_{alt.hourly} \tag{15}$$

Based on the above, the condition is defined as follows:

$$\frac{I_{swap}}{L_{rem}} + V_{swap} \times P_{fuel} \leq \frac{I_{alt}}{L_{alt}} + V_{alt} \times P_{fuel} \quad (16)$$

The hourly savings for the swap project engine compared to the stock engine have been determined:

Hourly savings (S_{hour}):

$$S_{hour} = C_{alt.hourly} - C_{swap.hourly} \quad (17)$$

$$S_{hour} = \left(\frac{I_{alt}}{L_{alt}} + V_{alt} \times P_{fuel}\right) - \left(\frac{I_{swap}}{L_{rem}} + V_{swap} \times P_{fuel}\right) \quad (18)$$

Hence, the total net savings (TS) over the entire remaining service life of the swap unit (L_{rem}) are calculated as the difference in normalized costs multiplied by the engine's resource:

$$TS = S_{hour} \times L_{rem} \quad (19)$$

$$TS = \left(\left(\frac{I_{alt}}{L_{alt}} + V_{alt} \times P_{fuel}\right) - \left(\frac{I_{swap}}{L_{rem}} + V_{swap} \times P_{fuel}\right)\right) \times L_{rem} \quad (20)$$

$$TS = \frac{I_{alt} \times L_{rem}}{L_{alt}} + (V_{alt} \times P_{fuel} \times L_{rem}) - I_{swap} - (V_{swap} \times P_{fuel} \times L_{rem}) \quad (21)$$

By substituting equations (4) and (5) into (22) and performing the necessary algebraic transformations, we obtain the final efficiency equation:

$$TS = \left(I_{alt} \times \frac{L_{rem}}{L_{alt}}\right) - I_{swap} + (P_{fuel} \times L_{rem} \times (V_{alt} - V_{swap})) \quad (22)$$

The mathematical efficiency model based on the remaining service life, incorporating the known specific fuel consumption at the selected engine power output, is presented as follows:

$$TS = \left(I_{alt} \times \frac{L_{rem}}{L_{alt}}\right) + \frac{P_{fuel} \times L_{rem} \times (g_{alt} \times N_{n.gen} - g_{swap} \times N_{eng.req})}{1000 \times \rho_{fuel}} - I_{swap} \quad (23)$$

The payback criteria are defined as follows:

If $TS > 0$: The project is economically viable and yields net savings in monetary units over the projected remaining service life.

If $TS = 0$: The project reaches the break-even point; the investment is recovered, but no additional savings are generated.

If $TS < 0$: The project is unprofitable; an overhaul of the stock engine is the preferred alternative.

To verify the viability of the developed functional relationship, baseline data from both the selected engine swap kit and the original engine were utilized.

For instance, the capital expenditures for a 4D68T swap engine (paired with a VAZ-2107 7-speed manual transmission) with a required power output of $N_{eng.req}$ = 33 kW and a predicted residual life L_{rem} of at least 3500 hours amounted to I_{swap} = 1779 m.u. In comparison, the restoration costs for the original D-246.1 engine with a power output of $N_{n.gen}$ = 42 kW and a service life L_{alt} = 10000 hours amounted to I_{alt} = 2500 m.u. Given a diesel fuel cost of P_{fuel} = 0.7 m.u. and fuel savings from the swap project totaling ΔV = 900 g/h.

By implementing the mathematical model's programmed code – incorporating the known volumetric (mass) fuel consumption rates V_{alt} and V_{swap} as defined by Equation (22), and the specific fuel consumption g_{alt} и g_{swap} derived from Equation (23) – and inputting the required variables, the efficiency (payback) graph for the selected swap project was obtained (Fig. 2).

On the graph, the ordinate (Y-axis) represents the net savings index TS. The X-axis represents the residual service life of the swap engine, L_{rem} (measured in engine hours).

The graph originates in the negative zone at – 1779 m.u, which corresponds to the initial capital investment for the purchase and installation of the swap kit I_{swap}.

The curve intersects the x-axis at approximately 1900 operating hours. This is the break-even point – a critical metric indicating that once this runtime is reached, the project has fully recovered the installation costs through fuel savings and depreciation advantages.

At the calculated milestone of 3500 hours, the graph reaches a value of +1690,12 m.u. This represents the net savings realized by the equipment owner beyond the initial costs of the swap project.

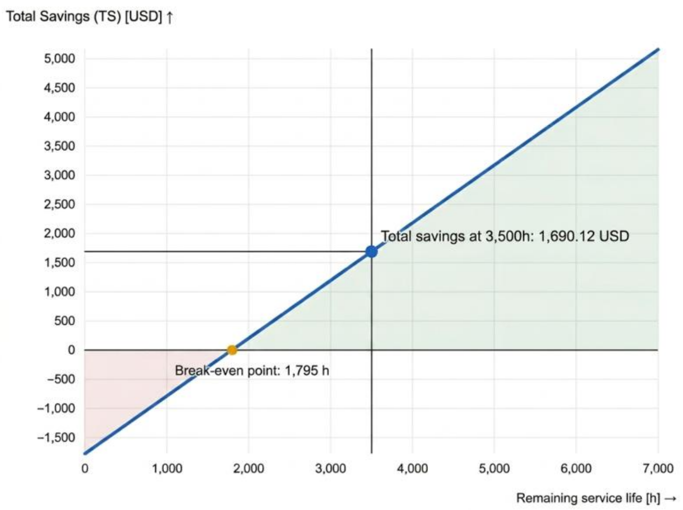

Fig. 2. – Economic efficiency of the project with a swap kit cost of 1779 m. units and a target operating time of 3500 hours, based on the 4D68T engine and the VAZ-2107 5-speed manual transmission

The fuel consumption reduction parameter ΔV = 900 g/h is the determining factor of efficiency and directly influences the geometry of the graph. Fuel economy dictates the steepness (gradient) of the line. The greater the difference in specific fuel consumption between the stock and swap engines, the steeper the upward slope of the graph. In this model, every gram of fuel saved acts to increase the angle of inclination, accelerating the transition out of the loss zone.

Due to the significant difference in consumption (900 g/h), the savings on fuel and lubricants quickly offset the initial investment. With lower fuel economy, the break-even point would shift to the right (e.g., toward 5000-6000 hours), thereby increasing the project's financial risks.

Conclusions

Based on the results of the study, the following conclusions have been formulated:

1. Capital Expenditures I_{swap} and I_{alt}. It is demonstrated that the low cost of a swap kit is a necessary but not sufficient condition for economic viability.
2. Operational Savings ΔV or Δg. The model mathematically substantiates the role of the manual transmission (MT) as a tool for optimizing operating modes and reducing fuel consumption, as confirmed by the $g = f(M, n)$ dependencies across various MT gears. It was established that high fuel efficiency of the swap kit is a critical factor that compensates for its lower residual service life compared to a new industrial engine.
3. Residual Service Life L_{rem}.. The inclusion of this parameter via the levelized hourly cost formulas (13 and 14) prevents errors when comparing projects with different amortization periods or lifespans.
4. Kinematic Analysis. The analysis confirmed that by selecting the optimal gear ratio (in this specific case, 3rd gear), the automotive engine is shifted into the range of maximum torque and minimum specific fuel consumption. This effectively mitigates the negative effects of operating in regimes that were not originally designed for stationary machinery.
5. Hypothesis Confirmation. The hypothesis that utilizing used automotive units is an effective resource-saving tool has been confirmed. This approach allows for a 3-to-5-fold reduction in initial capital investment and significantly shortens equipment downtime under conditions of limited access to new imported components.

The practical significance of the model lies in its ability to determine the boundary conditions under which a swap project becomes more profitable than traditional overhaul or repair.

Equation (23) indicates that the project generates a positive economic effect even with higher specific adaptation costs, provided that the difference in hourly fuel consumption and residual life is large enough to offset these expenses. Thus, the proposed model serves as a tool for techno-economic justification when designing drives for stationary machinery using secondary automotive resources.

The study provides an accessible engineering methodology for a rapid assessment of swap project feasibility based on current market prices for units and fuel. These results are recommended for implementation at enterprises operating small-scale power systems in remote regions and as a foundation for further research into the rational reuse of automotive industry resources.

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Information of the authors

Aimukhanov Damir Sapargalievich, doctoral student, Abylkas Saginov Karaganda Technical University
e-mail: adspavlodar@gmail.com

Mehtiyev Ali Javanshirovich, c.t.s., professor, Abylkas Saginov Karaganda Technical University
e-mail: barton.kz@mail.ru

Wargula Lukasz, professor, Poznan Polytechnic University
e-mail: lukasz.wargula@put.poznan.pl

Sembayev Nurbulat Sakenovich, c.t.s., associate Professor, Toraigyrov University
e-mail: n.sembaev@mail.ru

Aimukhanov Sapargali Mukhidenovich, c.a.s., professor, Toraigyrov University
e-mail: ads-pavl@mail.ru