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On the Issue of Efficiency of Shunting Diesel Locomotives at Cargo Terminals



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ABSTRACT

The main shunting operations at the cargo terminal compose of supply of cars for loading and their removal after unloading. The article describes the modes of operation of a shunting diesel locomotive performing these operations. The procedure for calculating in the form of an algorithm for determining performance indicators of a shunting locomotive is given, followed by the results of calculations for performing a technological operation of supplying cars for loading and removing them after unloading by a ChME3 diesel locomotive at the cargo terminal. The necessity of increasing the requirements for quality of control decisions made by drivers of shunting diesel locomotives is determined. The criterion for evaluating the use of one or another locomotive control mode has been adjusted.

These studies are aimed at ensuring control in the most efficient way, providing for a reduction in fuel consumption by shunting diesel locomotives and thereby reducing the cost of shunting work at the cargo terminal, the costs for owners of cargo terminals.

Also, a comparative analysis of the use of various options for controlling a diesel locomotive for the most common operation, supply of five cars for loading and their removal after unloading, at the cargo terminal under specified operating conditions is performed and presented. The cost of fuel saved through the use of a rational mode of control of a shunting locomotive has been determined.

Keywords: *transport, railway, operating modes of a diesel locomotive, modelling, shunting work at the cargo terminal, cost reduction.*

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As part of the digital transformation strategy of JSC Russian Railways, it is important to increase efficiency of production processes, use an expanded set of decision support tools with economic assessment of their efficiency, widespread use of decision support systems, in particular, software products for controlling shunting diesel locomotives in order to save fuel and reduce the cost of shunting work. Large cargo terminals provide services in a comprehensive way comprising shunting operations, loading, unloading, stowage and securing of cargo, storage, weighing, warehouse handling, road delivery [1]. The procedure for performing operations of supplying cars for loading and removing them after unloading is regulated by the contract. On non-public tracks with a small wagon turnover, these shunting operations, as a rule, are carried out on notification [2]. The supply of wagons for loading and their removal after unloading are carried out using shunting locomotives.

Operating mode of shunting locomotives [3, p. 73] consists of a combination of simple operations, each of which is a combination of single modes of the same form shown in Pic. 1 (acceleration R_{pj}, maintaining constant speed R_{dj}, coasting R_{uj}, braking R_{tj}, parking or maneuvering with a single locomotive R_{xxj}), differing in initial and final values, which are given in the form of a distribution of discrete random variables [4]. Modelling of the shunting operation of a diesel locomotive at the cargo terminal using a software product was carried out according to the developed method [4], simulates motion processes, traction processes and real processes in power plants with a selected degree of accuracy for each of the above-described single modes. This makes it possible to simulate the operation of a shunting locomotive without recalculating repetitive simple operations.

Indicators of any single mode can be determined by traction calculation [5, p. 28] on steady-state and transient modes with a time interval Δt:

$$dv/dt = \xi(F_k \pm w_k - b_b), \qquad (1)$$

where F_k is tangential traction force of the locomotive, N;

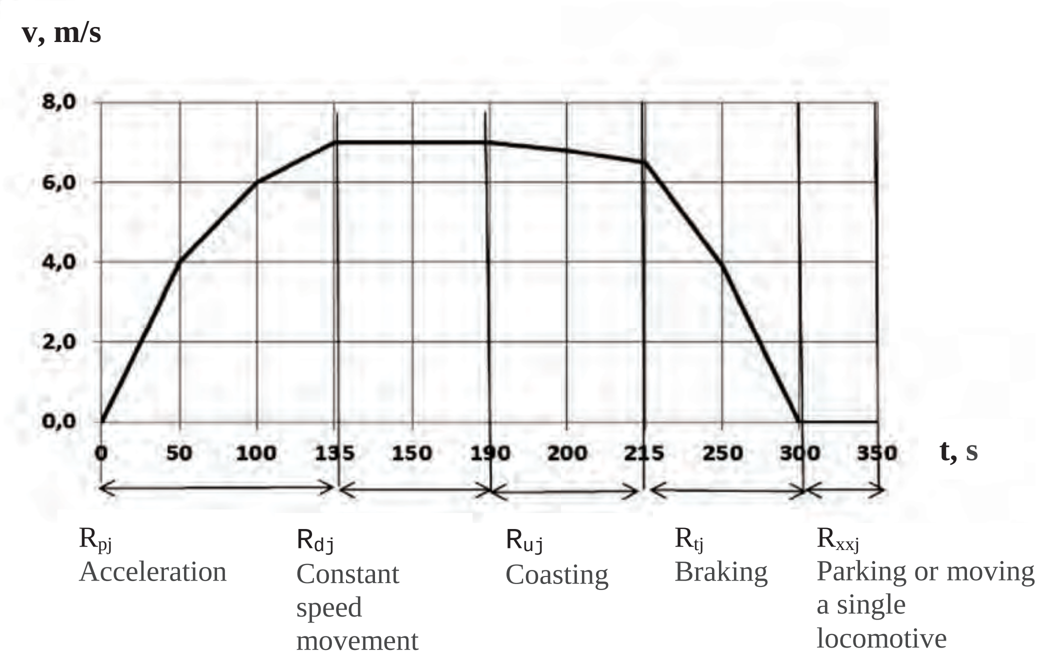
w_k – total resistivity, N/kg;

b_b – braking force, N.

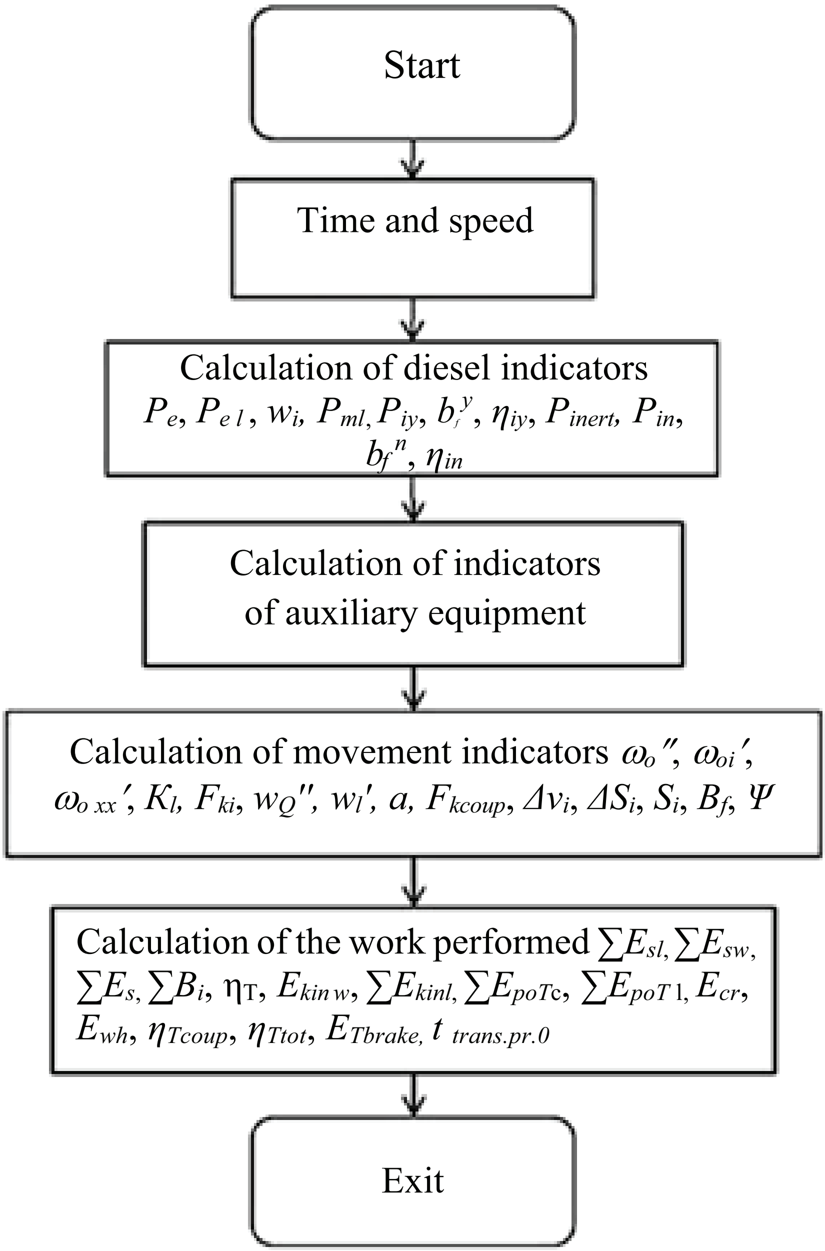
The operating time at a given controller position consists of short operating modes, in which there are practically no static modes. The locomotive runs for seconds at each position, the rest of time is occupied by transient processes.

For each single mode of operation of a diesel locomotive, algorithms have been developed (Pic. 2), which include calculation blocks comprising [6]:

• parameters of train movement using rules of traction calculations (RTC) and adhesion constraints v, F_k, dv/dt, dF_k/dt;



Pic. 1. Single modes.



Pic. 2. Block diagram of the algorithm for calculating a single mode.

• performance indicators of the power plant P_i, P_{ml}, b_f, K_l [7];

• operation of auxiliary units P_{aux};

• indicators of work performed and efficiency η_{cr}, η_{ml}, W_l, P [4],

where v – speed, s;

dv/dt – train acceleration, m/s;

dF_k/dt – angular speed, rad/s;

P_i – indicated power, W;

P_{ml} – power of mechanical losses, W;

b_f – fuel consumption, kg;

K_l – indicator of losses, m/s;

P_{aux} – power of auxiliary units, W;

η_{cr} – efficiency of a diesel locomotive on an automatic coupler;

η_l – overall efficiency of a diesel locomotive;

W_l – complex criterion (formula (2));

P – productivity, wagon/h.

In Pic. 2 the following designations are accepted:

P_e – effective power of the diesel engine at steady state modes, W;

P_{el} – calculated effective power of the diesel engine, W;

w_i – current value of the crankshaft rotation speed, rad/s;

P_{ml} – power of mechanical losses, W;

P_{iy} – steady state mode indicator power, W;

b_f^y – steady state mode fuel consumption, kg;

η_{iy} – steady state mode indicator efficiency;

P_{inert} – power of inertial forces, W;

P_{in} – indicated power in the transient process, W;

b_f^n – fuel consumption in the transient process, kg;

η_{in} – indicated efficiency in the transient process;

ω_o'' – specific resistance to movement of cars, N/kg;

ω_{oi}' – specific resistance to the locomotive movement, N/kg;

$\omega_{o\,xx}'$ – specific resistance to idle motion, N/kg;

K_l – indicator of losses, m/s;

F_{ki} – tangential traction force of the locomotive, N;

w_Q'' – resistance to movement of cars, N;

w_l' – resistance to movement of the locomotive, N;

a – train acceleration, m/s;

F_{kcoup} – tangential traction force of the locomotive with automatic coupler, N;

Δv_i – speed increment, m/s;

ΔS_i – path increment, m;

S_i – distance traveled, m;

B_b – braking force, N;

Ψ – coefficient of adhesion;

$\sum E_{sl}$ – dissipative work of a diesel locomotive, J;

$\sum E_{sw}$ – dissipative work of wagons, J;

$\sum E_s$ – total dissipative work, J;

$\sum B_i$ – diesel fuel consumption during transient and steady state conditions, kg;

η_T – diesel efficiency;

$\sum E_{kin\,w}$ – kinetic work of wagons, J;

$\sum E_{kin\,l}$ – kinetic work of a locomotive, J;

$\sum E_{poT\,w}$ – potential work of wagons, J;

$\sum E_{poT\,1}$ – potential work of the locomotive, J;

E_{cr} – work with automatic coupler, J;

E_{wh} – work on the wheel, J;

η_{Tcoup} – efficiency of a diesel locomotive with an automatic coupler;

η_{Ttot} – overall efficiency of the locomotive;

E_{Tbrake} – work of braking, J;

$t_{trans.pr.0}$ – time of the transient process, s.

Having performed the calculation of a single mode of operation of the locomotive according to the above algorithm, we obtain the results presented in the form of an automatically compiled summary table of operational performance of a locomotive performing a single mode operation and the table of distribution of fuel consumption and operating time of the locomotive by positions of the driver's controller [4].

For a typical shunting operation, using a set of basic characteristic single modes of a shunting diesel locomotive and varying the components, we obtain the final results in the form of a summary table of performing a shunting operation for the selected single modes, taking into account idling at standstill [4]. The summary table includes: name of the locomotive, mass of wagons in the train, time, distance, fuel consumption, dissipative work of wagons and locomotive, kinetic work of wagons and locomotive, braking work, potential work of wagons and locomotive, work with automatic coupler, work related to a wheel, efficiency of a locomotive when working with automatic coupler, overall locomotive efficiency, performance of the locomotive. Graphs of fuel consumption (B_f, $B_{f\,set}$) and time (T, T_{trans}) are also formed according to the positions of the driver's controller during an operation [4].

Using the final results of calculations, that is, the indicators of the work performed by diesel locomotives, it is possible to analyze and solve many problems aimed at choosing the most suitable diesel locomotive for the given operating conditions at the cargo terminal and its control mode, applying a complex criterion:

$$W_l = (B \cdot T)/m \rightarrow min, \text{ при } E_{cr} = const, \quad (2)$$

where E_{cr} – work performed by diesel locomotives with an automatic coupler, J;

B – fuel consumption, kg;

T – time, s;

m – number of wagons in the train.

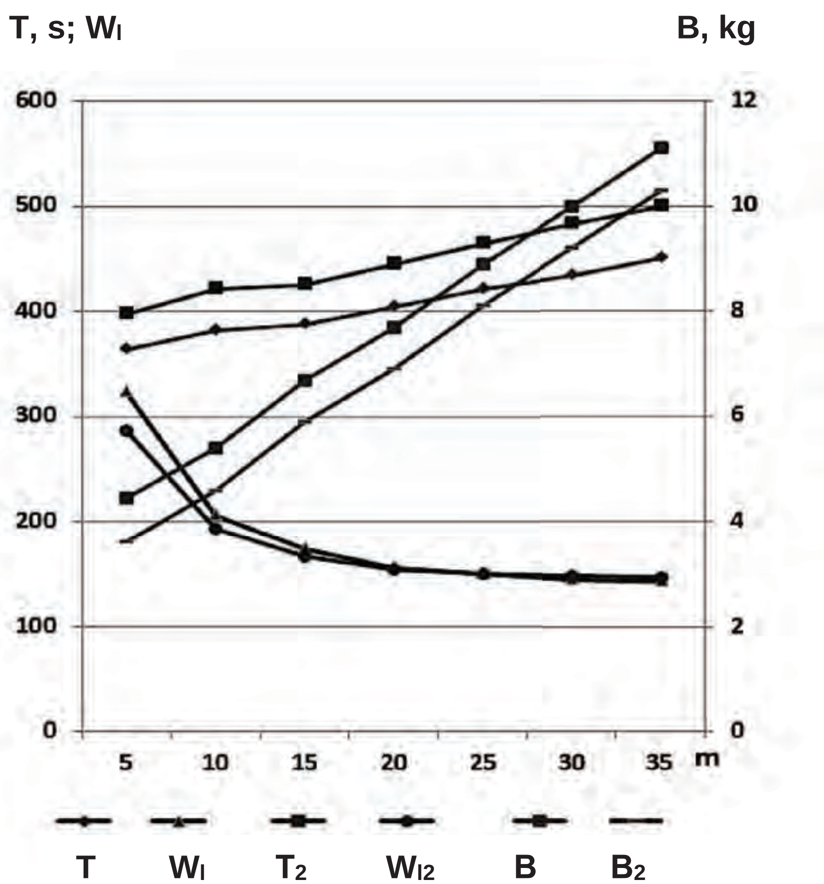
For example, the most common technological operation of supplying cars for loading and their removal after unloading at cargo terminals can be performed in different ways: with the acceleration to a given speed with maximum performance or with a given speed at a given position of the driver's controller (for example, 5 PC).

Table 1

Comparison of results of performing the technological operation of supplying cars for loading and their removal after unloading by ChME3 diesel locomotive with different variants of setting of positions of the driver's controller*

Number of cars	Performance indicators when using the acceleration mode to a given speed with maximum performance (Mode 1 (R1))			Performance indicators when applying the acceleration mode to a given speed at a given position (5) (Mode 2 (R2))		
m	Time, s, T	Fuel consumption, kg, B	Complex criterion, W_l	Time, s, T2	Fuel consumption, kg, B2	Complex criterion W_l2
5	363,2	4,5	323,2	397,8	3,57	286,4
10	381,2	5,4	205,8	421,2	4,6	193,8
15	387,1	6,7	172,9	425,1	5,9	167,2
20	404,3	7,7	155,7	445,2	6,9	153,6
25	421,2	8,9	149,9	463,7	8,1	150,2
30	433,1	10,0	144,4	482,5	9,2	148,0
35	450,3	11,1	142,8	499,3	10,3	146,9

Note: *the calculation was carried out under the same specified conditions, the distance traveled is 3000 m.



Pic. 3. Graphical representation of the change in the performance of the locomotive and the complex criterion W_l when performing the technological operation of supply of cars for loading and their removal after unloading.

Table 2

Comparison of the results of performing the technological operation of supplying cars for loading and their removal after unloading by the diesel locomotive ChME3 with different variants of the set of positions of the driver's controller (5 cars)

Route length	Performance indicators when using the acceleration mode to the specified speed at maximum speed (Mode 1 *(R1)*)			Performance indicators when applying the acceleration mode to a given speed at a given position (5) (Mode 2 *(R2)*)			ΔW_l
L	Time, s, T	Fuel consumption, kg, B	Complex criterion, W_l	Time, s, T2	Fuel consumption, kg, B2	Complex criterion, W_l2	
1520	299	3,39	202,72	266	2,39	127,15	75,57
3200	507,6	4,2	426,38	513,6	3,8	390,34	36,04

Drivers often have to operate a shunting locomotive [8, p. 68] in conditions of emotional stress and stressful situations due to impact of unfavorable factors and various kinds of interference, redundancy or lack of information, time constraints, high responsibility for ensuring safety and for the final result, which can lead to erroneous actions and that is reflected by an increase in fuel consumption. Therefore, in addition to monitoring and control systems for a diesel locomotive [9], the increased requirements for quality of control decisions, particularly those made by drivers, the need to process large amounts of information and streamline processes, predetermine introduction of autopilots on a shunting diesel locomotive [e.g., 10], automated control systems for them, in particular, the control mode selection block, which ensures a decrease in fuel consumption by using the most rational option for controlling the operating modes, and thereby reducing the cost of manoeuvres and costs for owners of cargo terminals (the tools for achieving this goal are described in [4]).

Let's choose a rational control mode for a shunting locomotive for specific conditions.

Table 1 shows the results of the calculation, according to the above-described algorithm, for the diesel locomotive of ChME3 type [11] equipped with ESUVT (electronic fuel injection system) that supplies wagons for loading and removes them after unloading under various control methods.

As can be seen from Table 1, for the given conditions with the number of wagons in the train less than 25, the second variant of performing the technological operation of supplying cars for loading and their removal after unloading with the mode of acceleration to a given speed at a given position is most preferable (5). The value of fuel economy [11] for the most common technological operation of supplying 5 cars for loading and their removal after unloading, calculated according to the Table 1 is determined by the formula:

$$\Delta B_p = B_{R1} - B_{R2}, \qquad (3)$$

where B_{R1} and B_{R2} – fuel consumption of the diesel locomotive in the first and second modes of performing the technological operation of supplying cars for loading and their removal after unloading by the diesel locomotive ChME3, respectively, kg.

$\Delta B_p = 4{,}5–3{,}57 = 0{,}93$ kg.

Cost of saved fuel is [4]:

$$C = P_l \cdot \Delta B_p, \qquad (4)$$

where P_l is price of 1 l fuel, 49 rub.

$C = 49 \cdot 0{,}93 = 45{,}6$ rub. per an operation of supply of 5 cars for loading and their removal after unloading.

In general, for the year the cost of the saved fuel, for operations of supplying 5 cars for loading and their removal after unloading, will be [4]:

$$C_{tot.f} = (365 - T_i) \cdot C \cdot k, \qquad (5)$$

where k – number of diesel locomotives (1 pcs.) at the cargo terminal;

T_i – idle time of a diesel locomotive during maintenance and repairs for a year, taken as Tp = 15 days.

$C_{tot.f} = (365–15) \cdot 45{,}6 \cdot 1 = 15960$ rub. per year for operations of supply of 5 cars for loading and their removal after unloading at one cargo terminal.

Taking into account the number of cargo terminals and the number of shunting operations in the country (company) as a whole, using the rational control mode of a shunting diesel locomotive incorporated in the control mode selection block, one can obtain a significant economic effect and reduce the cost of shunting work at cargo terminals.

Pic. 3 shows the critical point, the parameters of which confirm that when the number of wagons is more than 25, it is advisable to use the first option for performing the technological operation of supplying cars for loading and their removal after unloading with an acceleration mode to a given speed with maximum performance.

It can also be noted that the fuel saving from choosing a rational control mode for a shunting locomotive is more obvious when performing shunting work by short routes.

As a result of the research, a strategy was formulated to search for a rational type of diesel locomotive for a specific operation and to select its control mode depending on the object of research and operating conditions, in particular for cargo terminals. In each specific case, it is possible to choose the most rational, most economical option considering variety of operated locomotives [e.g., 12].

Experts of research organizations, manufacturers, and owners of shunting locomotives, and owners of cargo terminals should strive to introduce intelligent control systems for technical means involved in transportation processes, including for shunting work, to rationalize operational work, to implement in a flexible manner new technologies and approaches in a digital economy environment.

Conclusion

1. Simulation of processes of performing shunting operations at the cargo terminal allows with high reliability to calculate performance of a shunting locomotive, to clarify fuel consumption [4] and to identify the most rational modes of control of the locomotive according to the complex criterion W_l.

2. The calculation of the indicators of the shunting work of supplying cars for loading and their removal after unloading at the cargo terminal by the ChME3 diesel locomotive for the given conditions has been carried out, and the influence of operating modes of the shunting diesel locomotive on its fuel efficiency is graphically shown.

3. A comparative analysis of the use of different control modes of a shunting locomotive was carried out and the cost of the saved fuel for the most common technological operation of supplying 5 cars for loading and their removal after unloading at the cargo terminal was determined.

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