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IMPROVING LOCOMOTIVE UTILIZATION EFFICIENCY THROUGH THE OPTIMIZATION OF LOCOMOTIVE MAINTENANCE

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Introduction

The efficiency of locomotive utilization in the transport system is determined by their operational performance indicators. The main task of the locomotive complex is to ensure a continuous and reliable transportation process, in which technical condition, reliability, and maintenance quality play an important role. Locomotive operating efficiency is directly related to their technical and operational condition and to the maintenance and repair system. Therefore, optimization of locomotive utilization requires continuous analysis and management of their operational condition. As a result, transportation stability increases, idle time decreases, and overall transport efficiency improves.

Methodology

The process of conducting TS-2 maintenance inspections of electric locomotives on the electrified railway sections of JSC “Uzbekistan Railways” was analyzed. As a result, it was determined that the freight locomotives of the “Uzbekistan” series operating on the 14-km Kokand-Margilan railway section travel, mainly as light engine movements, to the Kokand locomotive depot, which is located 35 km from Margilan station, in order to undergo the scheduled TO-2 maintenance. When the locomotive travels between Kokand and Margilan stations at an average speed of 60 km/h, it takes approximately 40 minutes (0.67 h) to cover the 35-km distance in one direction. Therefore, a round trip as a light engine movement requires 80 minutes (1.34 h). Since 2.5-3.0 h are required to perform TS-2 technical inspection and maintenance of each locomotive, the total time spent for a single maintenance, including the round-trip light engine movement, amounts to approximately 4.5-5.0 h. TS-2 maintenance is performed at main and turnaround depots by workers of different specialties. The work includes inspection of locomotive components, lubrication, tightening of loosened parts, adjustment, and other maintenance operations. To perform these operations, approximately 1-2 h are

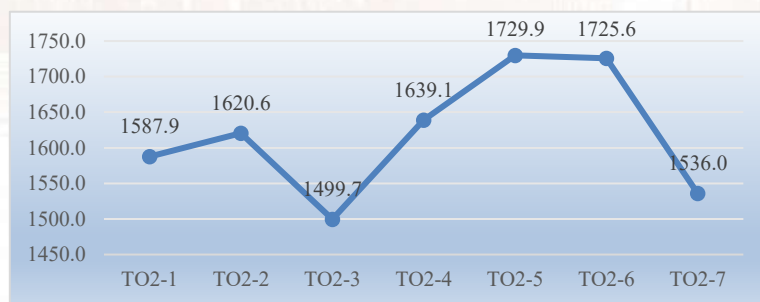
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allocated for freight locomotives and about 4 h for passenger locomotives. Each locomotive is required to undergo TO-2 maintenance every 24-48 h.

The estimated cost of a single TO-2 maintenance procedure, averaging approximately 8 million UZS, consists of several components. Labor costs account for 30-40%, including the wages of mechanics, electricians, brake specialists, and locomotive drivers, amounting to approximately 2.4-3.2 million UZS. Materials and spare parts constitute 25-35%, including lubricants, filters, gaskets, minor components, and cleaning materials, with an estimated cost of 2.0-2.8 million UZS. Energy costs account for 5-10%, covering electricity, compressor operation, and diagnostic equipment, and are estimated at 0.4-0.8 million UZS. Depreciation represents 10-15%, including the depreciation of depot equipment and lifting mechanisms, amounting to approximately 0.8-1.2 million UZS. Finally, locomotive downtime, which represents the largest hidden cost, accounts for 15-25% and includes lost revenue, the use of reserve locomotives, and schedule disruptions, corresponding to approximately 1.2-2.0 million UZS per TS-2 maintenance operation.

$$E = C_s + C_m + C_e + C_a + C_w \quad (1.1)$$

The study is based on statistical data collected by the authors over the period from March 1, 2024, to March 1, 2025 [1]. Figures 2, 3, and 4 present the theoretical curves of locomotive mileage between successive TO-2 technical maintenance inspections. The horizontal axis represents the distance traveled, expressed in kilometers, while the vertical axis indicates the frequency with which locomotives undergo TO-2 maintenance over a one-year period.



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Diagram 1: Mileage of the electric locomotive “O‘zbekiston” between TS-2 maintenance intervals during the first month, km.

During the month, the locomotive covered a mileage ranging from 1,587 km at the beginning to 1,536 km at the end, undergoing a total of seven TO-2 maintenance procedures during this period. Initially, the locomotive covered 1,587 km before the first maintenance procedure, while the lowest mileage, 1,499 km, was recorded before the third maintenance procedure. In the subsequent stages, a noticeable increase in mileage was observed: 1,639 km before the fourth maintenance procedure, 1,729 km before the fifth, and 1,725 km before the sixth. Finally, after the seventh maintenance procedure, the locomotive traveled approximately 50 km less than its initial mileage. Thus, throughout the month, the locomotive mileage fluctuated, while each TO-2 maintenance procedure was performed to ensure operational reliability and prevent potential failures. Based on the mileage between successive TO-2 maintenance procedures, the proposed approach would allow the locomotive to travel an additional 612 km, 580 km, 701 km, 561 km, 471 km, 475 km, and 664 km, respectively, resulting in a total additional mileage of 4,063 km. Consequently, the number of TO-2 maintenance entries would be reduced by two times, generating an estimated economic benefit of 16 million UZS during the month.

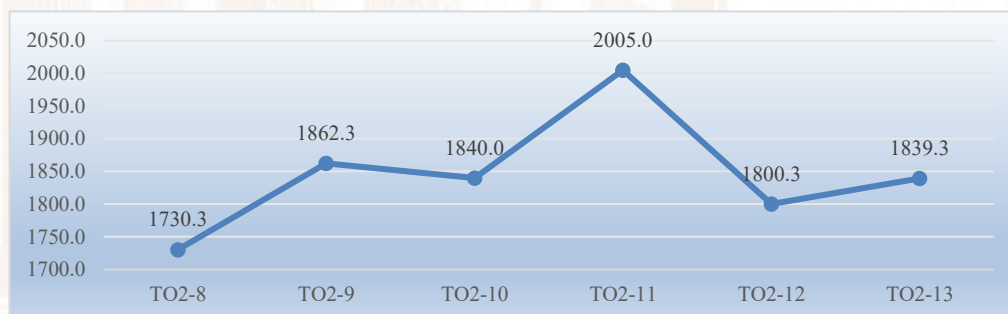


Diagram 2: Mileage of the electric locomotive “O‘zbekiston” between to-2 maintenance intervals during the second month, km.

By the second month, the locomotive began operating over relatively longer distances, reaching the highest mileage recorded during the study period of 2,005 km in the middle of the month. The mileage increased from 1,730 km before the first maintenance entry and continued to rise, reaching its maximum value before the fourth



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TO-2 maintenance procedure. This value was approximately 200 km higher than the mileage recorded before the fifth TO-2 maintenance procedure.

During the month, the locomotive underwent six TO-2 maintenance procedures, with a mileage of 1,839 km recorded before the final maintenance entry. According to the proposed approach, the locomotive would have the potential to travel an additional 430 km, 338 km, 330 km, 195 km, 400 km, and 361 km, respectively, between successive TO-2 maintenance procedures, giving a total additional potential mileage of 2,054 km. With the possibility of covering an additional 2,054 km, the locomotive would require only five TO-2 maintenance procedures instead of six during the month. This reduction in the number of maintenance entries would result in an additional cost saving of approximately 8 million UZS.

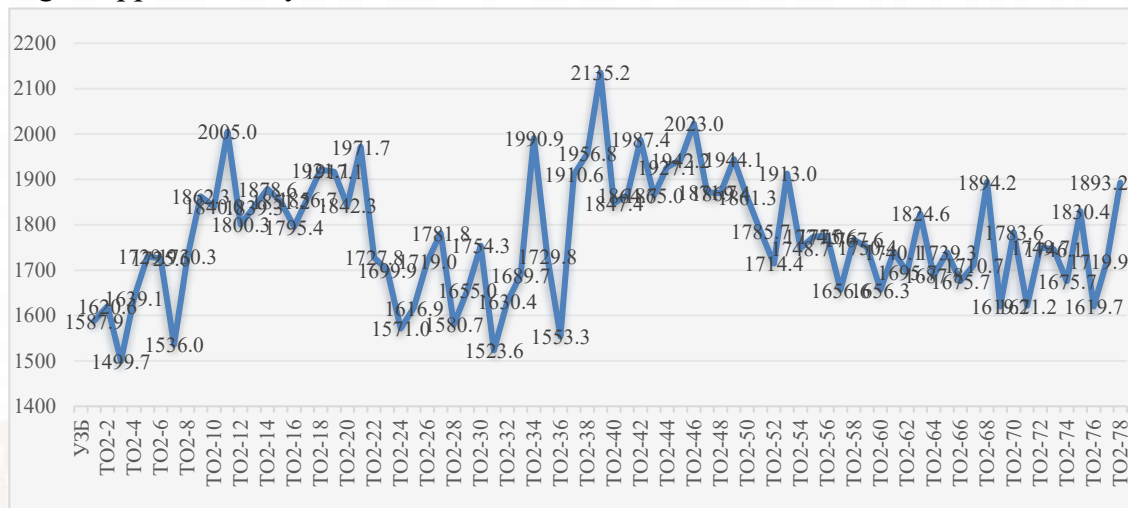


Diagram 3: Mileage of the electric locomotive “O‘zbekiston” between to-2 maintenance intervals over one year

Diagram 3 illustrates that the electric locomotive “O‘zbekiston” underwent TO-2 technical maintenance 78 times over the course of one year. At the beginning of the year, the locomotive recorded its lowest mileage between TO-2 maintenance procedures, at 1,499.7 km. Although a relatively high mileage value of 2,135.2 km was recorded in the middle of the study period, indicating a higher level of locomotive utilization, the subsequent mileage values generally remained within the range of approximately 1,890-2,000 km.

$$E \text{ O'zbekiston 1 year} = E1 + E2 + \dots + E12 = 16 \text{ mln} + 8 \text{ mln} + \dots + 8 \text{ mln} = 160 \text{ mln. UZS}$$

Based on the arrival times of freight trains at the locomotive turnaround point ($t_{\text{turn.p.c}}$) and their departure times ($t_{\text{turn.p.l}}$), the duration of locomotive stay at the turnaround point was determined in accordance with the normative dwell time (for example, $t_{\text{turn.p.d}} = 0.5$ h). The calculation was performed according to the following sequence.

Firstly, it was checked whether a freight train locomotive arriving at the beginning of the day could be coupled to the first departing train, using the following condition:

$$t_{\text{turn.p.l}} - t_{\text{turn.p.c}} \geq t_{\text{turn.p.d}}, h \quad (1.2)$$

If this condition was satisfied, according to the first-stage modelling results for 30 pairs of trains, the locomotive arriving with train No. 2002 at 00:40 was coupled to train No. 2001, which was scheduled to depart at 01:54 (Figure 1). Considering that, for the given 30 pairs of trains, locomotives operating in the even-numbered direction undergo TO-2 technical inspection every four days after arriving at the turnaround point, the locomotives of trains No. 2002, 2008, 2016, 2022, 2030, 2038, and 2046 are sent for TO-2 technical inspection on the first day, respectively.

As a result, the locomotives of trains arriving in the odd-numbered direction are coupled to locomotives of subsequently arriving trains after the locomotive scheduled for maintenance has entered the repair facility. Taking into account all operations required during the TO-2 technical inspection, the locomotive returns to the turnaround section after an average of 7 h and is coupled to the train arriving at the same time.

The results of the first-day modelling showed that the total dwell time of freight locomotives at the turnaround point was 17 h 30 min., while the total waiting time of freight train consists for departure from the turnaround point amounted to 44 h 40 min.

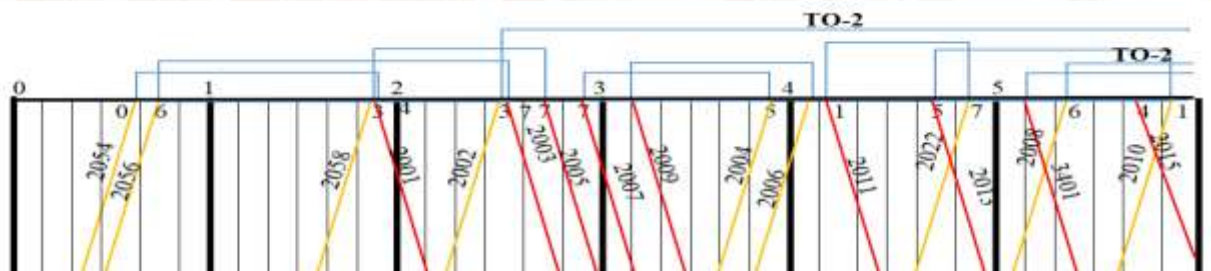


Figure 1. Fragment of the dwell time of locomotives and train consists at the turnaround point under the existing operating conditions

For the given 30 pairs of trains, after the locomotives operating in the even-numbered direction arrive at the turnaround point, the second-stage modelling considers

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the condition of assigning locomotives to TO-2 technical inspection based on the mileage they have covered. As a result of changing the existing practice of performing TO-2 technical inspections every four days, the locomotive of every fifth arriving train is assigned to TO-2. Accordingly, during the first day, the locomotives of trains No. 2012, 2020, 2030, and 2040 are sent for TO-2 technical inspection. The modelling results showed that the total dwell time of freight locomotives at the turnaround point was 14 h 48 min, while the total waiting time of freight train consists for departure from the turnaround point amounted to 35 h 20 min.

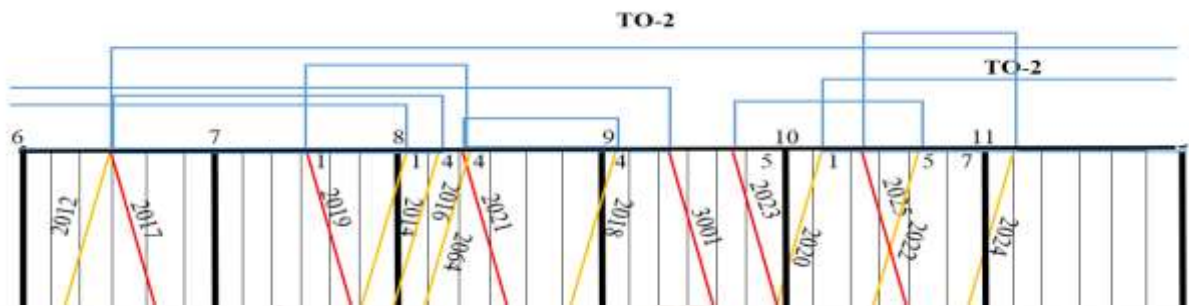


Figure 2. Fragment of the dwell time of locomotives and train consists at the turnaround point under the proposed operating conditions

Table-2

Results of determining the average dwell time of locomotives and train consists at the “A” turnaround point for different modelling scenarios For the calculation, the cost rates were assumed as follows: 140,962 UZS per locomotive-hour ($C_{el-l} = 140,962$ UZS), 973 UZS per car-hour ($C_{v-c} = 973$ UZS), and the number of cars in a train consist was taken as $m = 62$ cars.

Number of trains	Alternative	$\bar{t}_{turn.loc}$, hour	$\bar{t}_{turn.wag}$, hour	Locomotive-hour costs	Train-consist-hour costs	Total costs
1	2	3	4	5	6	7

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30	i	17 h, 30 min.	44 h, 40 min	2466835	2694762	5161597
	$i+1$	14 h, 48 min.	35 h, 20 min	2086237	2131317	4217554

Thus, under a paired train timetable, the dwell times of locomotives and train consists at turnaround point “A” can be calculated automatically using the method described above. When the method includes several simulation stages, the most economically efficient alternative can be selected using the following expression:

$$E = N_t \cdot (\bar{t}_{turn.loc} \cdot e_{l-c} + \bar{t}_{turn.wag} \cdot m \cdot e_{w-c})$$

where m is the average number of wagons in a freight train, wagons;

e_{l-c} , e_{w-c} – the respective cost rates per locomotive-hour and car-hour.

To evaluate which alternative is economically preferable, it is advisable to plot changes in locomotive-hour costs, train-consist-hour costs, and total costs [5].

Conclusion

The dwell time of train locomotives at a station constitutes an integral component of the locomotive turnaround time within the operating section. Therefore, reducing the dwell time has a positive effect on reducing the operating locomotive fleet, i.e., the number of locomotives required for operation, as well as the costs associated with maintaining locomotive crews.

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