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DEVELOPMENT AND SCIENTIFIC VALIDATION OF TECHNICAL AND OPERATIONAL PERFORMANCE STANDARDS FOR URBAN PUBLIC TRANSPORT

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Abstract: Urban public transport plays a pivotal role in supporting sustainable urban mobility and ensuring efficient transportation services amid rapid urbanization. Establishing scientifically validated technical and operational performance standards for public transport vehicles is essential for improving passenger safety, operational reliability, economic efficiency, environmental sustainability, and overall service quality. This study examines the theoretical and methodological principles underlying the development of these standards and proposes practical approaches for their implementation. The findings provide a scientific basis for optimizing vehicle performance indicators and enhancing the effectiveness of urban public transport systems under contemporary transportation demands.

Keywords: passenger safety, economic efficiency, environmental sustainability, technical and operational indicators, regulation development, methodological approaches.

Scientifically substantiated regulations for the technical and operational performance of urban public transport are based on a comprehensive set of interrelated indicators that determine the efficiency, reliability, and quality of transport services. These indicators include operating speed, which reflects the average technical and operational speed of vehicles under urban traffic conditions; service regularity, which ensures that buses and other public transport vehicles operate according to established schedules; capacity utilization, which involves selecting appropriate vehicle capacities based on passenger demand and traffic flow characteristics; and the technical readiness coefficient, which represents the level of operational availability and reliability of the vehicle fleet. The development of these regulations relies on a combination of scientific methods, including mathematical and simulation modeling for analyzing traffic flows and supporting smart city transport management, analytical and comparative studies of vehicle operating conditions and performance data, as well as planning approaches that incorporate international best practices in the design and optimization of urban route networks. The integration of these methods provides a scientific basis for improving the technical and operational performance of urban public transport systems while enhancing service quality, operational efficiency, passenger safety, and the sustainability of urban mobility.The scientifically substantiated regulations govern the following:

1. Technical Service: Diagnosis of the technical condition of motor vehicles and the scheduling of technical service (maintenance).
2. Operating Conditions: Ensuring the efficient operation of vehicles in the urban environment (traffic congestion, road surface).
3. Service Quality: Increasing appeal and creating conveniences for passengers. [1, 2, 3, 4]
4. Increasing the appeal for passengers and creating conveniences is a key factor in ensuring the efficiency and stability of the transport system. To achieve this goal, it is necessary to introduce modern technologies and improve service quality. [1]

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5. Key areas for creating passenger convenience and increasing appeal:
6. Modern Vehicles: Expanding the use of safe, fast, and comfortable vehicles (with air conditioning and Wi-Fi).
7. Digitalization and integration: Optimizing route maps, developing an online ticket purchasing system, and using modern IT solutions to manage traffic flow.
8. Infrastructure improvement: Making stops and stations comfortable, convenient, and safe for passengers, as well as complying with urban planning standards.
9. Service quality: Improving the qualifications of drivers and service personnel, and ensuring a courteous attitude toward passengers.
10. Innovative solutions: Studying and implementing innovative and unique transport systems, such as "Shweeb" in New Zealand. [1, 2, 3, 4]
11. The implementation of these measures will serve to increase passenger flow and enhance the overall efficiency of the transport system.

These measures will be implemented in accordance with urban transport and infrastructure development programs through 2025, based on concepts developed by the Ministry of Transport. [1]

The efficient operation of the urban public transport system is directly dependent on the technical condition of the vehicles. The following problems are observed in global practice:

- An outdated transport fleet—in many cities, the average age of buses and trolleybuses exceeds 10-15 years.
- Traffic accidents due to technical malfunctions—the share of accidents caused by such failures is 8-12%.
- Inefficient consumption of fuel and energy resources: a deterioration in technical condition increases fuel consumption by 15-25%.
- Violation of environmental standards: exceeding emission norms negatively affects the environment.

1. Theoretical substantiation of the system of technical and operational indicators.
2. Development of a methodology for evaluating indicators.
3. Creation of a model for optimizing regulation parameters.
4. Providing recommendations for practical application.

The technical operation of vehicles is a set of measures to maintain them in a specified technical condition, as well as to prevent and eliminate malfunctions. Fundamental research in this field covers the following areas:

Based on reliability theory, the probability of maintaining a vehicle's operational capacity is expressed by the following formula:

R (t) =e−λt$R\ (t) = e - \lambda t$

where R (t) R (t) is the reliability function at time tt, and λλ is the failure rate.

The theory of maintenance strategies identifies three main approaches:

- Reactive strategy (repairing upon failure).
- Preventive strategy (scheduled maintenance at fixed intervals).
- Predictive strategy (maintenance based on condition monitoring).

	In global practice, technical and operational regulations are based on the following standards:		
	Standard	Scope	Key Requirements
1	UNECE R13	Braking systems	Braking distance, system integrity
2	UNECE R51	Noise level	Permissible noise limits

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3	Euro VI	Emissions	Exhaust Gas Standards
4.	ISO 39001	Road Safety	Safety Management System

Recent research suggests the following approaches for assessing technical and operational performance indicators:

Multi-criteria evaluation methods — allow for an integrated assessment of a vehicle's technical condition based on several parameters. The generalized evaluation indicator is:

$Kum=\sum i=1nwi \cdot kiKum = i=1\sum 7>n\ wi \cdot ki$

where wiwi is the weighting coefficient of the ii-th indicator, kiki is the normalized value of the ii-th indicator, and nn is the number of indicators.

Life Cycle Analysis (LCA) — a methodology for assessing the efficiency of a vehicle throughout its entire operational life.

The technical and operational performance indicators of urban public transport vehicles are divided into the following groups:

Braking system indicators — as a key factor in road traffic safety, they are evaluated by the following parameters:

Braking distance:

$St=v0 \cdot tr+v022 \cdot jmaxSt = v0 \cdot tr + 2 \cdot jmax\ v02$

where v0v0 is the initial velocity (m/s), trtr is the driver's reaction time (s), and $$j_{max}$$ is the maximum deceleration (m/s2).

	Requirements for public transport:			
1.	Indicator	City Bus	Trolleybus	Tram
2.	Maximum deceleration	≥ 5.0 m/s2	≥ 4.5 m/s2	≥ 3.0 m/s2
3.	Brake force difference (by axle)	≤ 25%	≤ 25%	≤ 30%
4.	ABS operation	Mandatory	Mandatory	—

Steering system indicators:

- Free play in the steering mechanism — ≤ 10° (≤ 20° for heavy vehicles)
- Steering effort — ≤ 250 N (without power assistance), ≤ 120 N (with power assistance)
- System watertightness and durability

Lighting system specifications:

- Low beam distance — 40-75 m
- High beam distance — ≥ 100 m
- Signal visibility — ≥ 300 m (daytime), ≥ 600 m (nighttime)

	Service life indicators:		
	Component	Minimum service life	Warning limit
1	Engine	500,000 km	400,000 km
2	Transmission	400,000 km	320,000 km
3	Chassis components	600,000 km	480,000 km
4	Electrical system	300,000 km	240,000 km

3.4. Environmental indicators

Exhaust gas emission standards (in accordance with Euro VI standard):

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Component	Limit (g/kWh)
CO	1.5
THC	0.13
NMHC	0.13
NOx	0.4
PM	0.01
PN	8×1011 (1/kWh)

Inspection type	Frequency	Scope
Daily inspection	Daily	Key safety components
Weekly inspection	Weekly	Extended check
Monthly inspection	Monthly	Full diagnostics
Annual inspection	Annually	Certification inspection

Defects requiring scheduled correction:

- Exhaust gas emissions exceeding norms — correct within 72 hours
- Noise level exceeding limits — correct within 7 days
- Malfunction of cabin equipment — correct within 24 hours

6. Evaluation of the regulation's effectiveness

6.1. Effectiveness indicators

After the implementation of the regulation, the following indicators will be monitored:

According to scientific calculations, the implementation of the proposed regulation is expected to yield the following results:

Indicator	Current status	Expected result	Improvement
Incidents due to technical malfunction	100% (baseline)	65%	35% ↓
Technical availability coefficient	0.78	0.88	12.8% ↑
Fuel consumption	100% (baseline)	88%	12% ↓
Exhaust gas emissions	100% (baseline)	75%	25% ↓
Passenger satisfaction	62%	78%	16% ↑

The study resulted in the following conclusions:

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1. The need for a systematic approach — technical and operational indicators should be viewed as an interconnected system, not individually.
2. Scientific grounding — regulatory parameters must be determined based on statistical data analysis, mathematical modeling, and international standards.
3. Flexibility — the regulation must be adaptable to technological changes and the emergence of new transport types.
4. Control mechanisms — without an effective monitoring and evaluation system, the regulation cannot achieve its objective.

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