Management of the bus fleet structure in modern conditions

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Abstract. The full disclosure of the potential capabilities of buses requires an assessment of the effectiveness of their operation for a number of relevant requirements. The modern regulatory and technical framework for the operation of buses provides high requirements in accordance with environmental and safety standards throughout the life cycle. Therefore, today, the bus fleet structure management system should consider indicators of the quality of their operation, as well as the design stage, in the process of operation and subsequent disposal. Accordingly, the properties of the bus, which are part of the quality, should be practically implemented (correlated) in accordance with the variable parameters of the operating environment over the entire life cycle. At present, taking into account the technical and operational indicators of buses, it is averaged to change the individual groups of indicators of quality, as for an individual object, and for their totality in the structure of the park. The fundamental difference between the developed hierarchy of goals and the subsystems of the control structure system of a bus is to take the level of traditional complex quality criteria into account - to ensure reliability, such as environmental and structural safety and the ability to implement an environmentally sound business environment.

1. Introduction
The widespread use of road transport and its technological and organizational advantages over other modes of transport require improving the structure of the rolling stock of motor transport enterprises [1-4]. When determining the structure of the bus fleet, it is necessary to rely on the fact that the rolling stock is most consistent with natural and climatic conditions; road conditions; and a regulatory framework that limits the operation of buses in specific conditions; ensuring maximum efficiency and traffic safety, etc.

A systematic approach to the methods of designing the structure of the bus fleet dictates the need for not formal, but purposeful management of its optimization processes depending on operating conditions. A certain combination of transportation conditions in a particular region or even in a separate micro-district of a megalopolis requires the use of a certain bus model that could provide maximum efficiency according to several relevant criteria: environmental and structural safety, fuel economy, reliability, performance, transportation costs, comfort, etc. d. In this case, it is necessary to take into account the following specific features of the structure of the bus fleet in the Russian Federation. Buses, since the release of which more than 5 years have passed, accounted for 78% of the fleet, including with a life of more than 15 years - 44%, more than 20 years - 33% (figure 1). Thus, in order to ensure that the Russian fleet of buses meets modern technical and environmental requirements, it is necessary to stimulate enterprises to acquire new cars. In this regard, amendments are being developed to the Federal Law “On Road Traffic Safety” (regarding the establishment of time limits for the operation of vehicles), in particular, it is proposed to introduce a rule prohibiting the use of vehicles that have reached the time
limits for the operation of buses and to determine such time limits taking into account transitional periods (not more than 15 years).

Figure 1. The age structure of the bus fleet in the Russian Federation according to the traffic police.

Thus, in order to find the optimal structure of the bus fleet today, it is necessary to take into account not only several relevant performance criteria, but also systematically manage the process of timely decommissioning of buses.

2. Problem statement
The solution of these urgent tasks of managing the structure of the bus fleet in modern conditions encounters two main difficulties.

The majority of scientific approaches to managing the structure of a car fleet are based on multifactor single-criterion models that determine the laws governing the formation of a fleet of buses by one comprehensive quality indicator - reliability. The analysis of the actual state of the modern bus operating environment has shown that the existing scientific and methodological foundations for managing the fleet structure do not meet the generally recognized world requirements for its adaptation to the multicriteria environmental conditions of operation and the requirements of scientific and technological progress. The absence of theoretical and methodological provisions for managing the structure of the bus fleet according to several performance criteria requires the development of a set of adequate mathematical models to ensure their effective, constructive and environmentally safe operation.

The current methods for managing the age structure of the bus fleet, when planning the processes of technical operation, use the value of the resource or mileage before the cancellation of buses determined by the automakers. At the same time, the indicators of technical maintenance (TM) and current repairing (CR) should be updated by bus explant enterprises. In particular, the CR specific labor intensity indicator is not regulated for foreign-made buses or has a significant range of possible solutions (for domestic-made buses). The value of this indicator affects the size and capacity of the production and technical base, determined by the availability of necessary equipment, appropriate staff qualifications, etc. The unreasonable use of this indicator in the planning of the production program for the technical operation (TO) of buses leads to unreasonably high costs for the operation of vehicles. In addition, regulatory documents are regularly updated, requiring increased environmental friendliness and safety of bus operation, which directly affects the terms of their operation through the specific CR labor intensity
indicator. Therefore, it is necessary to develop and apply a scientifically-based apparatus for making optimal decisions in the applied task of structuring the bus fleet.

3. Research questions
The full disclosure of the potential operating capabilities of all automotive vehicles requires evaluating the effectiveness of a number of properties of an integrated quality state. The modern regulatory and technical base for the operation of buses makes high demands on the conformity of its properties to environmental and safety standards throughout the entire life cycle. Therefore, today, the bus quality system should form the structure of performance indicators, both at the stage of its design development, and in the process of operation and its subsequent disposal. Accordingly, the properties of the bus, which are part of its quality, should be practically realized (correlated) in accordance with the changing parameters of the operating environment throughout the entire life cycle of the car. The formation of the rolling stock fleet should be based on a quantitative assessment of the basic laws associated with the formation of the concept of the quality of operation of the bus, as well as factors that affect the implementation of quality.

Traditionally, in the Russian Federation, to assess the level of quality, all industrial products are classified as objects of research into two classes (products consumed in use and products that consume their resources) and into five groups characterized by a limited set of types of determining indicators. Cars in accordance with this classification belong to the fifth group - repaired products. This group contains 15 groups of indicators of product quality [5]. In [6], a significant list of passenger car quality indicators is given. It is necessary to note that the separate groups of indicators highlighted such groups of indicators as: safety indicators and indicators of environmental impact. The relevance of this campaign is confirmed by an increasing number of studies and publications on this topic. In [7], a technique for assessing the quality of a car according to individual groups of indicators is presented, while the classification of parameters is carried out, containing 22 points. In [8], the mandatory requirements for vehicle safety in operation are classified by five particular operational safety features. The following is noted: “during operation, several systems of operational safety requirements for automatic telephone exchanges are objectively necessary, each of which is “tied” to certain technological capabilities and inspection conditions ...”. Thus, it determines the possibility of making an independent decision on the feasibility of using individual private operating properties, which forms the objective need for a multi-criteria assessment of the quality of operation of any car. For buses, the implementation of this approach is especially relevant.

In science, the technical operation of automobiles (TOA), the basis of quality assessment is the comprehensive characteristic of the product - reliability, reflected in a number of properties, the main of which are reliability, durability, maintainability, and storage [9]. The change in the quality state of the car is described by the dependence [10]:

\[
\Pi_k(t) = \Pi_{k1} \cdot e^{-k(t-1)},
\]

where \(\Pi_k(t)\) and \(\Pi_{k1}\) are qualities at the t-th and first year of operation; k is coefficient identifying the intensity of changes in quality indicators over time (mileage); t is duration of operation, years.

Naturally, the vast majority of the properties of buses deteriorate as they age, which affects the quality indicators of not only a specific object, but also of a higher system - the car park. At the same time, as the bus advances in the production-operation-utilization complex (as it ages), the intensity of the change in quality indicators is an unstable process in time. Loss and renewal of individual properties may occur, criteria may change when a vehicle transitions from one state to another. Therefore, to simplify the quality management procedures over time, as a rule, the quality of the bus over the life of the car is averaged in the form of an implemented quality indicator [11].

The implemented quality indicator is the average value of the quality indicator for a certain period of operation of the bus.

\[
\Pi_k(t) = \frac{\Pi_{k1}e^k}{t} \sum_{t=1}^{\infty} e^{-kt}.
\]
where $\Pi_k(t)$ and $\Pi_{k_1}$ are qualities at the t-th and first year of operation; $k$ is coefficient identifying the intensity of changes in quality indicators over time (mileage); $t$ is duration of operation, years.

The initial values of quality indicators implemented during the operation of buses are laid during production and taking into account the requirements of operating conditions. The intensity of their change is determined by the design parameters during production, as well as to a large extent by the state of the external environment (SEE) of operation. SEE operation affects the intensity of changes in quality indicators through numerous factors, determined by: maintenance and repair methods, quality of maintenance and repair, used operating materials, driving style, etc. The action of the majority of resource and technological factors of SEE is subject to this law. A sufficiently rigorous mathematical justification for the "attenuation of the effect" can be obtained using the "Markov" processes and their properties [12]. It is important to emphasize that the nature of the instability in time of the main properties of the bus is determined not only by the heterogeneity of the groups of indicators of technical and operational properties, but by the varying intensity of their change depending on the mileage or the operating life.

According to the data presented in [13] according to the intensity of change, complex and unit indicators are divided into three main groups.

- Having an insignificant rate of change (from 0.9 to 1.1): costs of operational materials; release factor; specific downtime for maintenance and repair.
- Having a significant rate of change (from 1.5 to 5.0): reliability indicators, as well as indicators characterizing the performance of the car.
- Having a pace leading to a change in the indicator within the range of close or exceeding the order with respect to the initial value (from 7 to 20 or more): the specific labor of the TP, the consumption of spare parts and replaced parts and their total cost.

The first group includes indicators that provide such operational efficiency parameters: technical readiness coefficient, output coefficient, specific simple maintenance and repair. The second group includes indicators characterizing the reliability of components and assemblies and, thus, ensuring the performance and technical safety of the operation of the bus. The third group of indicators characterizes mainly the essence of qualitative changes that occur during aging of the product (cost of replaced parts, consumption of spare parts). This group of indicators is more responsible for the environmental safety and constructive safety of the bus while tightening the requirements of the operating environment.

Nevertheless, at present, the average rate of the implemented quality indicator change is being considered and taken into account, that is, the rate of change of individual groups of quality indicators is being averaged, both for an individual bus and for their combination. The realized quality indicator at the $i$-th interval of mileage or service life is determined as:

$$\bar{\Pi}_{kl} = \frac{\Pi_{k1}(1+\sum_{i=1}^{n} K_{cp}^{i-1})}{i},$$

(3)

where $\Pi_{k1}$ is the initial value of the quality indicator; $K_{cp}^{i-1}$ is the average rate of change of the bus quality indicator; $i$ is reference year or mileage interval number.

4. Methods of research

The formed alternative management system for the structure of the bus fleet should meet the basic management principles that determine its functions.

- The definition and achievement of the goal facing the management should be carried out in the framework of the program-targeted approach. The essence of the program-target method used to solve managerial problems is to integrate all types of activities of the subsystems in the form of a program to achieve the goal [14].
• Obtaining information on the state of the system and on external factors acting on the system and determining the SHS. The goals set for the system can be achieved by various methods, so it is important to identify factors that contribute to their achievement and to establish among them a certain sequence or share of implementation, taking into account the degree of significance of each factor for the system to achieve its ultimate goal.
• Processing information about the state of the system and the SHS in order to determine its accuracy and reliability.
• Making management decisions based on methods appropriate to the degree of information certainty or uncertainty about the SHS, in accordance with the objectives of the system and the information received and processed.
• Bringing the solution to practical implementation, through certain standards and their correction through regulatory documents.
• The implementation of the control action in the form of organizational and technological impacts.
• Obtaining the response (reaction) of the control system in the form of new information (feedback), which is processed, analyzed, and based on it, a new solution is applied or the previous one is adjusted.

Consequently, the process of achieving the goals of the bus fleet structure management system through control actions should be step-by-step, iterative. In other words, the goal of the bus fleet structure management system is to ensure the process of converting information about the quality of the bus according to the operating environment according to a number of relevant criteria into targeted actions that translate the managed object from its initial state (designed in accordance with current regulatory documents) to the optimal state - to compliance with the objective requirements of the operating environment developed over a specified period of operation.

The formation of new tasks in any control system inevitably entails changes in its structure. The general theory of systems establishes that the management structure of complex systems is hierarchical (multi-level) in nature. In the hierarchical structure, the question of the optimal number of elements subordinate to the senior element and located at the same level is extremely important. The more such elements, the less controllable the system, but, on the other hand, the creation of a greater number of hierarchy seniority levels is also undesirable, because it will lead to a long process of information passing [15,16].

In the first case, in order to maintain the controllability of the system, it is necessary to develop a mathematical apparatus aimed at finding an effective solution and allowing to formulate optimization algorithms for control processes in the system taking into account several criteria. In the second case, when moving from level to level, the number of tasks to be solved is usually reduced, but their importance and complexity significantly increases. The criteria for the tasks of the junior level should be consistent with the interests of the senior level of management. The practical implementation of this method is often associated with significant difficulties, because not always, having risen to a higher level, it is possible to formulate and solve the corresponding single-criterion optimization problem.

Based on the fact that the hierarchy structure of the vehicle fleet management system should be built with the smallest possible number of steps, and controllability in the system should be provided with an adequate mathematical apparatus, it is advisable to determine the hierarchy of the system and the boundaries of the study.

5. Results and discussion
Figure 2 shows the decomposition of the hierarchy of the control system, based on the above principles and within the framework of the program-targeted approach.

Within the framework of one scheme, it is quite difficult to group all the components of this complex system; therefore, the individual TMA indicators for individual quality criteria are not shown in the hierarchy shown in the diagram. The boundaries of this system are determined by a large number of
SEE factors, and, consequently, by the large dimension and order of the tasks being solved. The choice of input and output streams, the level of their aggregation, and mathematical modeling of the control apparatus in the system should be consistent with the purpose of the control system. Therefore, the analytical model of the vehicle operation quality management system should be formalized so that the input and output flows at its borders are elementary, and the criteria used in establishing the system boundaries are identified and justified by the scope of this study [17].

\[
\Pi^{(1)} = \Pi_0^{(1)} e^{-\beta_1 t} \\
\Pi^{(2)} = \Pi_0^{(2)} e^{-\beta_2 t} \\
\Pi^{(3)} = \Pi_0^{(3)} e^{-\beta_3 t}
\]

where \( \Pi^{(1)} \) – quality indicator, reflecting property structural safety of car operation; \( \Pi^{(2)} \) – quality indicator reflecting environmental safety; \( \Pi^{(3)} \) – quality indicator reflecting technical condition, \( \Pi_0 \) – indicator value at the beginning of operation, \( \beta \) – coefficient characterizing the change in property over time.

**Figure 2.** Decomposition of the hierarchy of the bus fleet structure management system.

6. **Conclusion**

The fundamental difference between the presented hierarchy of goals and the subsystem of the management system in figure 2 is the leveling with the traditional integrated quality criterion - ensuring the reliability of the bus, criteria such as environmental and structural safety. At the same time, the number of hierarchy levels remains constant, that is, the flexibility of the system remains unchanged [11, 13], but to preserve the initial control parameters of the system, a multicriteria task is formed that requires an analytical solution. The solution of this problem allows us to assess the conformity of the
quality of the bus to the operating environment, in case of a change in the latter, the parameters of the operating efficiency change [17]. The practical implementation of this approach is possible only if we take into account the computational aspects associated with this approach and based on the properties of a continuous non-decreasing function. If we imagine the dependence of the value of the quality indicator on the bus mileage in the form of a continuous non-decreasing function $f_k(l)$, then:

$$\frac{\int_{l_1}^{l_2} f_k(l) dl}{l_2} \leq \frac{\int_{l_1}^{l_2} f_k(l) dl}{l_2-l_1}$$

(4)

where $l_2$ – bus mileage at the time of the planned technical impact, km, $(l_2 - l_1)$ – interval between exposures.

$$\Pi_{kij} = \frac{1}{d_{ij}} \sum_{j=1}^{m} p_{kij} \cdot 1000, \text{ quantification/1000 km}$$

(5)

In accordance with this method, the assessment of the quality of buses during their operation will occur iteratively in accordance with the change in SEE. The results of this assessment are aggregated into the multicriteria task of managing the structure of the bus fleet.

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