Maintenance and repair management taking into account specialization, cooperation and unification within a united bus company consisting of several branches

N V Pozhivilov¹, V A Maksimov¹, G A Krylov¹ and A A Zavgorodniy²

¹Moscow Automobile and Road State Technical University (MADI), 64, Leningradsky ave., Moscow, 125319, Russia
²Research Centre, Mosgortrans, 22/21, b. 1, Raushskaya naberezhnaya, Moscow, 115035, Russia

E-mail: poj-nikita@mail.ru

Abstract. The issue of maintenance and repair management of fleet in a bus transit agency consisting of several branches is presented in the article. Technical base development takes place due to increasing of effectiveness as a result of specialization and cooperation of maintenance and repair, as well as using maximum potential, reducing and optimal costs allocation. The minimum total reduced cost was taken as a criterion for the efficiency of production placement, focusing on the costs associated with the choice of specialization and subsequent cooperation of maintenance (mainly the costs of transportation of units and vehicles between the branches). The management approach of cooperating in the issue of maintenance and repair of buses is aimed at the distribution of a particular type of work between the technical bases of different branches of the united transit agency. The applied method is based on the common approach to the solution of the “transport problem” and adapted specifically for the united transport company involving two and more separate branches. The method was tested on the united agency operating urban buses in Moscow, aiming to allocate fleet maintenance with regard to its needs and resources.

1. Introduction

The main goal of the development and improvement of the technical base of a transit agency is to increase the efficiency of the technical base based on specialization and cooperation in maintenance and repair of fleet due to the maximum use of the existing technical potential, reduction and rational use of capital investments.

The directions that determine the form of organization of the technical base include [1–6]:

- concentration of the technical base;
- specialization in the types of maintenance and repair;
- cooperation of different technical departments of transit agency;
- creation of a centralized service for fleet maintenance and repair.

Concentration of a technical base shall lead to a concentration of the production funds necessary for ensuring fleet technical readiness and creation of conditions of high-performance human labor within the company [3].
Distribution of the scope of work on maintenance and vehicle repairs leads to the creation of new facilities at a higher organizational, technical and technological level, while the number of departments, shops and sections in the overall structure of the united enterprises is reduced, but their grade, staffing and technical equipment are significantly increasing.

A transit agency with incomplete maintenance or repair works is suitable only when the organization of some technical activity is economically unreasonable, i.e. when the establishment and support of the full program of technical base requires significant capital investments, the use of expensive equipment, large production areas.

Distribution as a condition for improving the technology and organization of production would not be acceptable with any consolidation company, but one that is accompanied by a decrease in the diversity of its products or service. This can be achieved by concentrating technologically uniform production or service.

The main goal of the specialization is to create such a concentration of uniform service at the company that allows for the most efficient use of high-performance equipment and technology. Specialization is characterized by the similarity of the technological process, the equipment, the qualification and occupational structure of the staff.

Two or more agencies can work in cooperation providing each other with mutual services for the maintenance and repair performance. Cooperation in such cases will make it possible to increase the degree of utilization of fixed assets and reduce the total costs of the technical requirements.

There is internal and external cooperation [1]. Internal cooperation shall take into account the cooperation of the most labor-intensive technological processes within the framework of individual transit agencies. External cooperation involves the vehicles repair and its units at other specialized shops and technical bases.

The article discusses the advisability of creating a concentration of specialized service for fleet maintenance or repair due to the internal cooperation of several branches (various territorial agencies) of a united transit agency. Territorial sites are subsidiaries which operate the fleet of city buses that provide passenger transportation on a fixed network of regular routes, and also have its own technical base, whose potential is sufficient to complete the main scope of the maintenance and repair of buses.

2. Different approaches to creating the conditions for specialization, distribution and cooperation of fleet maintenance and repair at transit agencies

Labor productivity is increased and costs are reduced as a result of concentration and specialization.

According to the expert assessment, the following preferable sequence of concentration of types of repair and preventive activities was identified [7]:

- Maintenance – the most preferable for concentration.
- Engine repair.
- Repair of fuel equipment; aggregate repair and tire repair.
- Repair of electrical equipment and gearbox repair
- Ongoing repair and daily maintenance – less preferable for concentration.

Types of repairs are specified from highest priorities to the least preferable for the types of work concentration and centralization.

The total effect of all organizational and technical measures caused by the specialization should be taken into account when evaluating the effectiveness of specialization of works, sites and zones separately as well as in general.

Specialized posts have the highest level of mechanization of work and the level of throughput, but they can carry out technological operations of a limited range. Therefore, specialized posts are organized at transit agencies with a large amount of fleet [6].

There are 4 types of specialization in automobile transport agencies [2]:

- Specialization by the type of the vehicle provides for maintenance and repair of a transport of a specific type of land transport, for example, buses, trolley-buses and trams.
- Specialization by brands when vehicles of the same brand are being repaired.
- Specialization by structural elements when one enterprise concentrates maintenance of similar parts regardless of the type and brand of vehicles. For example, repair of diesel fuel equipment, hydraulic or automobile electrical equipment, crankshafts, gearboxes, etc.

- Specialization by maintenance processes for the implementation of a specific type of work: general mechanical works, diagnostic, tire, etc.

Specialization and concentration are limited since as the concentration increases the cost of part transportation to the maintenance place increases significantly. In addition, the organization and production technologies have a significant impact on this process [8]. In addition, the level of specialization and concentration affect each other being in a correlation and influence transportation costs [9].

It is recommended to take a minimum total reduced costs as a criterion for the efficiency of service management. Meanwhile, it is needed to take into account operating costs, the necessary capital investments connected with the required changes as well as the costs connected with the choice of specialization option and subsequent cooperation (mainly, transportation costs of units and vehicles).

The rational allocation of different shops and labor force in branches of the united transit agency consists of optimal allocation of specific types of maintenance and repair works, ensuring a minimum of the total reduced costs.

The distance of an economically viable transfer of a bus from the i-th place (for example, company location) to centralized maintenance can be calculated as follows [5]:

$$l_{ij} \leq \frac{C_{kai} - C_{kat}}{2S^a(1 - \beta_{ij}^a)}$$

where $C_{kai}$ – specific reduced costs for the k-th type of bus maintenance at the j-th placement point (site);

$C_{kat}$ – the same in a centralized maintenance;

$S^a$ – prime cost of 1 km of the bus run;

$\beta_{ij}^a$ – the capacity utilization of the run when driving a bus from the i-th to the j-th point and back.

3. Methodology for the rational distribution of the scope of bus maintenance by branches at the united bus company

Given the limited capital investments as well as the fact that reconstruction and technical re-equipment are carried out under the conditions of existing transit agency, it is advisable to carry out specialization stage-by-stage with the priority development of those organizational and technological forms that provide the maximum efficiency increase. At the same time, the stages of specialization of technical base should be coordinated in such way that the previous stage creates technological and resource prerequisites for the effective development of subsequent stages. The overall effect of specialization should be maximum.

The analysis of actual and normative fleet downtime allows the company to identify the specific processes of maintenance that cause excessive downtime, establish the causes and outline a way to reduce downtime and justify the specialization of the various territorial technical bases (located in different branches) of the united transit agency during the development.

In general, an integrated approach for creation of the technical base system in a united transit agency based on specializations and cooperation in bus maintenance provides the following main steps [5]:

- Determination of the organizational and technological forms of a rational system for centralized fleet maintenance.

- Determination of the main types of specialization for each element of the technical base.

- Establishment of a rational structure and optimal capacity of technical base of united transit agency.

- Determination of the scope of work performed by different branches within the cooperation.

- Development of an approach to create a centralized system for the supply, maintenance and repair of technological and engineering equipment.
The achievement of this goal shall meet the needs for the complete and necessary maintenance and repair work of the fleet in order to achieve the planned value of the coefficient of technical readiness with rational costs for the operation of technical base branches.

This task of optimization of the fleet maintenance system can be solved by following the five steps:

I step. Initial data formation
The following initial data is necessary for optimal concentration and cooperation:
- Data for calculating the required labor and production capacity needed to provide the fleet maintenance in a united transit agency.
- Specific costs for the maintenance of technical equipment for each base of the united transit agency.
- Specific costs for bus and its units transportation between different technical bases of the united transit agency.

The initial data can be implemented as shown in table 1 (in the case of the united transit agency consisting of the three branches with their own technical bases as an example).

| Braches of united transit agency | Specific costs for bus transportation, rub. | Specific costs for one maintenance, rub. | The maximum capacity of annual amount of maintenance, qt. | Planned annual amount of maintenance by specific branch, iqt. |
|----------------------------------|--------------------------------------------|----------------------------------------|-------------------------------------------------|--------------------------------------------------|
| №1                              | \( C_{12} \) \( C_{13} \) \( - \)          | \( C^{M}_1 \)                           | \( T^{H}_1 \)                                   | \( T_1 \)                                         |
| №2                              | \( C_{12} \) \( - \) \( C_{23} \)          | \( C^{M}_2 \)                           | \( T^{H}_2 \)                                   | \( T_2 \)                                         |
| №3                              | \( - \) \( C_{13} \) \( C_{23} \)          | \( C^{M}_3 \)                           | \( T^{H}_3 \)                                   | \( T_3 \)                                         |

\[ \sum T^{H}_i \leq \sum T_i \] (1)

where \( C_{12} \) – specific costs for bus transportation between branch no. 1 and branch no. 2.
\( C_{13} \) – specific costs for bus transportation between branch no. 1 and branch no. 3.
\( C_{23} \) – specific costs for bus transportation between branch no. 2 and branch no. 3.
\( C^{M}_1 \), \( C^{M}_2 \) and \( C^{M}_3 \) – specific costs for one maintenance on branch no. 1, branch no. 2 and branch no. 3 respectively.
\( T^{H}_1 \), \( T^{H}_2 \) and \( T^{H}_3 \) – the maximum possible annual amount of maintenance potentially possible on branch №1, branch no. 2 and branch no. 3 respectively.
\( T_1 \), \( T_2 \) and \( T_3 \) – planned annual amount of maintenance by specific branch for buses operated on branch №1, branch no. 2 and branch no. 3 respectively.

II step. Identifying the possibility of optimization
The minimum prerequisite reflecting the opportunity to provide maintenance of the united transit agency:

\[ \sum T_i \leq \sum T^{H}_i . \] (1)

Only if (1) is satisfied, it is advisable to proceed to the third step.

III step. Formation of restrictions allowing for the performance of all the maintenance works on a full scale
The total amount of maintenance of buses operated at branches no. 1, no. 2 and branch no. 3:

\[ \begin{align*}
   x_1 + x_2 + x_3 &= T_1 \\
   y_1 + y_2 + y_3 &= T_2 \\
   z_1 + z_2 + z_3 &= T_3
\end{align*} \] (2)
where $x_1$, $x_2$, and $x_3$ are the volumes of maintenance for the fleet operated on branch no. 1 and are made on branch no. 1, branch no. 2 and branch no. 3, respectively.

$y_1$, $y_2$, and $y_3$ are the volumes of maintenance for the fleet operated on branch no. 2 and are made on branch no. 1, branch no. 2 and branch no. 3, respectively.

$z_1$, $z_2$, and $z_3$ are the volumes of maintenance for the fleet operated on branch no. 3 and are made on branch no. 1, branch no. 2 and branch no. 3, respectively.

Then the maximum amount of maintenance of buses performed at the technical base on branch no. 1, branch no. 2 and branch no. 3:

$$
\begin{align*}
x_1 + y_1 + z_1 & \leq T_1^H, \\
x_2 + y_2 + z_2 & \leq T_2^H, \\
x_3 + y_3 + z_3 & \leq T_3^H.
\end{align*}
$$

The cost of performing the maintenance at the technical base on branch no. 1:

$$
\sum C_1^M = C_1^M \cdot x_1 + \left( C_1^M + C_{12} \right) \cdot y_1 + \left( C_1^M + C_{13} \right) \cdot z_1.
$$

The cost of performing the maintenance at the technical base on branch no. 2:

$$
\sum C_2^M = \left( C_2^M + C_{12} \right) \cdot x_2 + C_2^M \cdot y_2 + \left( C_2^M + C_{23} \right) \cdot z_2.
$$

The cost of performing the maintenance at the technical base on branch no. 3:

$$
\sum C_3^M = \left( C_3^M + C_{13} \right) \cdot x_3 + \left( C_3^M + C_{23} \right) \cdot y_3 + C_3^M \cdot z_3.
$$

**IV step. Target function generation (minimum of total costs).**

Target function has to be represented as follows:

$$
\sum C_1^M + \sum C_2^M + \sum C_3^M \rightarrow \text{min}.
$$

It is necessary to find $x_1$, $y_1$, $z_i$ that satisfies the target function (4) and condition restrictions (2) and (3).

**V step. Finding an optimal solution using the transport problem approach.**

The optimization problem was solved by constructing a support plan and its improvement by the method of potentials. Eventually, such $x_1$, $y_1$, $z_i$ were found when constrains (2), (3) are implemented as well as target function (4) is achieved.

Analytical manual solution of a transport problem of a large scale (by the number of “consumer-suppliers”) can be difficult due to the large number of actions necessary to obtain an optimal plan. It is advisable to use special software or conduct calculations online on the Internet using one of the many web sites to automate the calculation [9].

**VI step. Analysis of eventual results**

The analysis of the obtained results has to be carried out and the decision of the optimal allocation of work between different technical bases of transit agency has to be made. When deciding in favor of the optimization there should be the model of organizational measures aimed at systematic and rational embodiment of the resulting model optimization.

### 4. Collecting initial data for the calculation of the rational allocation of fleet maintenance by the example of the maintenance zone of the united transit agency in Moscow

Approbation of the methodology was carried out at the united transit agency including three branches with their own technical bases. The transit agency operates urban bases on regular routes in Moscow. The goal was to obtain the system of rational allocation of maintenance by shares on three technical bases. The special point of the task was that such type of work had been stopped on the 1st technical base and the calculation according to the methodology should give the results meeting such constrains and propose the solution when the eventual allocation of shares of the fleet maintenance between two other technical base are optimal. The economic effect is not compulsory, but preferable in this specific task.
The initial data was collected by the following stages. 

*On the 1st stage* the costs on bus transportation between technical bases were calculated (table 2).

**Table 2.** Costs on bus transportation between technical bases (branches) of united transit agency in Moscow

| Bus transportation route | The length of transportation route, km | Fuel consumption, lit. | Fuel consumption costs, rub. | Full operational costs of the transportation, rub. |
|--------------------------|--------------------------------------|------------------------|-------------------------------|----------------------------------|
| between no. 1 and no. 2  | 6.5                                  | 2.1                    | 82.7                          | 330.8                            |
| between no. 1 and no. 3  | 10                                   | 3.24                   | 127.7                         | 510.8                            |
| between no. 2 and no. 3  | 11                                   | 3.6                    | 141.8                         | 567.2                            |

Further consumptions are made:
- Fuel consumption of bus LiAZ-529222 – 32.4 lit/100 km.
- Average cost for 1 lit of fuel – 39.4 rub.
- Fuel consumption is 25% of full operational costs.

*On the 2nd stage* the planned annual amount of maintenance of buses operated on three branches has to be calculated. The data is recommended to be presented on a year according to annual maintenance program and fleet write-off and supply (table 3).

*On the 3rd stage* the maximum capacity of maintenance by technical bases of all branches (2nd and 3rd branches in our case) was calculated. The data was provided by the transit agency based on the previous period of work.

Obtained data (*I step. Initial data formation*) allow us to carry out a calculation according to the proposed methodology and allocate the full amount of maintenance by shares on different technical bases.

**Table 3.** Initial data for optimal allocation of maintenance by technical bases of three branches of a united transit agency in Moscow

| Branches of united transit agency in Moscow | Specific costs for bus transportation, rub. | Maintenance |
|--------------------------------------------|--------------------------------------------|-------------|
| Specific costs of one maintenance of bus, rub. | The maximum capacity of annual amount of maintenance, qt. | Planned annual amount of maintenance by specific branch, iqt. |
| C_{i} | T_{i} | T_{i} |
| No1 between no. 1 and no. 2 | 662 1 022 – | 53 053 | 0 | 1 187 |
| No2 between no. 1 and no. 3 | 662 – 1 134 | 54 114 | 1 602 | 898 |
| No3 between no. 2 and no. 3 | – 1 022 1 134 | 51 992 | 1 958 | 1 230 |

In total 3 560 3 315

5. **Rational distribution of amount of bus maintenance by branches at the united transit agency in Moscow**

**II step. Identifying the possibility of optimization**

The minimum prerequisite to reflect the opportunity to provide maintenance of the united transit agency was examined to be as follows:

\[ 3 \ 315 \leq 3 \ 560 \]  \hspace{1cm} (5)

(5) is satisfied, it means that the goal is achievable and there are no obstacles to go further to the III step.

**III step. Restrictions allowing performing maintenance in full scale.**

The total amount of maintenance of buses operated at branches no. 1, no. 2 and branch no. 3:
Then the maximum amount of maintenance of buses performed at technical bases on branches no. 1, no. 2 and branch no. 3:

\[
\begin{align*}
    x_1 + x_2 + x_3 & = 1877 \\
    y_1 + y_2 + y_3 & = 898 \\
    z_1 + z_2 + z_3 & = 1230
\end{align*}
\]

(6)

The cost of performing the maintenance at the technical base on branch no. 1:

\[
\sum C^M_1 = 53053 \cdot x_1 + (53053 + 662) \cdot y_1 + (53053 + 1022) \cdot z_1 .
\]

The cost of performing the maintenance at the technical base on branch no. 2:

\[
\sum C^M_2 = (54114 + 662) \cdot x_2 + 54114 \cdot y_2 + (54114 + 1134) \cdot z_2 .
\]

The cost of performing the maintenance at the technical base on branch no. 3:

\[
\sum C^M_3 = (51992 + 1022) \cdot x_3 + (51992 + 1134) \cdot y_3 + 51992 \cdot z_3 .
\]

IV step. Target function (minimum of total costs)

The target function is presented as:

\[
\sum C^M_1 + \sum C^M_2 + \sum C^M_3 \rightarrow \min .
\]

(8)

It is necessary to find \(x_i, y_i, z_i\) that satisfies target function (8) and condition restrictions (6) and (7).

V step. Finding an optimal solution using the transport problem approach.

The solution of the transport problem is reduced to the online data input [9], analysis and solution of the problem.

Optimal plan is performed as follows:

\[
X = \begin{bmatrix}
0 & 459 & 728 \\
0 & 898 & 0 \\
0 & 0 & 1230
\end{bmatrix}.
\]

VI step. Analysis of eventual results.

The eventual result obtained according to the initial data and the proposed methodology is the allocation of shares of the fleet maintenance at the technical base of every branch of the united transit agency:

1. Planned amount of maintenance of buses operated at branch no. 1 is 1 187 of whose amount shall be:
   - 459 (around 39 %) amount of maintenance is optimally conducted at technical base of branch no. 2;
   - 728 (around 61 %) amount of maintenance is optimally conducted at technical base of branch no. 3.

2. Planned amount of maintenance of buses operated at branch no. 2 is 898 and the entire scope of work (100 %) is optimally conducted at the in-house technical base of branch.

3. Planned amount of maintenance of buses operated at branch no. 3 is 1 230 and the entire scope of work (100 %) is optimally conducted at the in-house technical base of branch.

The goal has been achieved because the whole scope of the fleet maintenance can be fully completed using the proposed allocation by just two technical bases at branch no. 2 and no. 3. Moreover, operational costs after the optimization do not exceed the operational cost before it. However, economic effect is not mandatory in the specific observed case; a small saving can be achieved (175.23 against 175.51 million rubles) that made the result profitable.

6. Conclusion and further recommendation
The article presents the topical issue of an optimal allocation of the fleet maintenance and repair works at a united transit agency operated urban buses through concentration, specialization and cooperation. Literature research shows that such issue is relevant as more and more transportation companies aim to reduce their operational costs and use rational approach of maintaining the fleet at an appropriate level of reliability.

Minimum of the total operational cost of a united transit agency has been taken as a criterion of optimality taking into consideration the full scope of the fleet maintenance.

The method of optimal allocation of maintenance at a united transit agency has been developed and implemented on transportation company operated buses in Moscow. The summary or the proposed methodology is as follows:

- initial data collection that include transportation costs between branches, specific costs of a single maintenance procedure for bus, annual amount of maintenance, planned annual amount of maintenance by specific branch;
- identifying the possibility of optimization;
- obtaining an optimal allocation through calculating the minimum specific cost and compliance with restrictions that guarantee a fully performed maintenance at the entire fleet of a united transit agency.

The proposed method has been implemented at a united transit agency operating urban buses in Moscow and consists of three branches with their own technical bases. After applying the method the optimal allocation of the shares of maintenance between branches has been found: relocation of the full scope of fleet maintenance from branch no. 1 to branch no. 2 (39 %) and to branch no. 3 (61 %), whereas the whole scope of the fleet maintenance from branches no. 2 and no. 3 is recommended to perform on their in-house technical bases.

References

[1] Won Il Lee 2018 The effect of external technology cooperation and internal relation on innovative behavior in technology intensive organizations *International journal of engineering & technology* 7(4.4) 26–9

[2] Kravchenko I N 2005 *Fundamentals of designing operational enterprises* (Moscow)

[3] Kournikov I P, Kuznetsov E S 1989 *Development of the technical base of road transport* (Moscow)

[4] Haedo C and Mouchart M 2017 A stochastic independence approach for measuring regional specialization and concentration *Regional Science* 97(4) 1151–68

[5] Napolsky G M 1993 *Technological design of motor transport enterprises and service stations* (Moscow: Transport)

[6] Kuznetsov E S, Voronov V P and Boldin A P 1991 *Maintenance of automobiles* (Moscow: Transport).

[7] Bergman A K 1975 *Efficiency and methods of formation of organizational and production structures of associations in urban passenger transport* (Moscow: Dissertation)

[8] Pozhivilov N V, Maximov V A, Krylov G A and Zavygorodniy A A 2019 Methodological approach to the rational distribution of work on maintenance and repair of fleet of the united motor transport enterprise *Problems of technical operation and car service of rolling stock of automobile transport* ed L L Zimanov (Moscow: MADI) pp 23–6

[9] Aiginger K, Rossi-Hansberg E 2006 Specialization and concentration: a note on theory and evidence *Empirica* 33 255–66

[10] *Minimum Transportation Cost Calculator*. Retrieved from: https://www.easycalculation.com/operations-research/minimum-transportation-least-cost-method.php.