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The “Engineer” publishes the most significant results of scientific and applied research carried out in universities of transport profile, as well as other higher educational institutions, research institutes, and centers of the Republic of Uzbekistan and foreign countries.

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Optimizing route loading by rationally allocating resources in the public transport system and meeting passenger demand

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Abstract: This article examines the issue of efficient distribution of 110 buses in the public transport system of the Republic of Karakalpakstan along five main routes. In order to rationally plan bus resources, a two-stage, simple calculation-based FRESET (Frequency Rationalization for Efficient Scheduling of Entire Transit) model was proposed. In the first stage of the model, the minimum number of buses sufficient to cover the daily passenger demand for each route was determined. In the second stage, the remaining excess buses were redistributed in proportion to the passenger flow and load level. According to the results of the study, 43 buses were distributed to five routes based on specific criteria, and the quality of service on some routes was significantly improved. In particular, the load level on routes such as R1 and R3 was optimized, waiting times were reduced, and overall balance was ensured. The proposed FRESET model is recommended as a practical, simple, and widely applicable solution for organizing regional transport networks.

Keywords: public transport, bus distribution, transport model, FRESET, Karakalpakstan, passenger demand, route optimization, heuristic method, logistics, transport service quality

1. Introduction

Public transport systems in countries are of social importance, playing an important role in ensuring population mobility, supporting economic activity and contributing to environmental sustainability. In Uzbekistan, public transport is mainly organized by the state, but decisions in the sector are often made based on short-term needs and the existing situation. This leads to poor quality of public transport services, imbalances in bus allocation and failure to meet passenger demand [1], [2].

Inadequate distribution of buses across the network results in overcrowding on some routes and inefficient use of the service on others. In particular, in intercity and regional routes, buses are often distributed on the basis of unmarked criteria, which causes problems in providing services to the population [3], [4].

International experience shows that optimizing the transport network and properly distributing buses along routes increases population mobility and allows for efficient use of resources. For example, Ceder and Wilson (1986) proposed a model for determining frequency based on route load and demand for bus network scheduling [5], [6]. Fan and Machemehl (2004) proposed a model for restructuring the network based on load balance [7]. Bashar and Garcia (2012) proposed solving bus distribution on interconnected routes through a simulation model [8].

In the Republic of Karakalpakstan, Uzbekistan, transport flows have increased significantly in recent years. At the same time, buses are unevenly distributed across routes: some routes have a load factor of more than 100%, while others are only used by 40–50%. This situation reduces economic efficiency and creates inconvenience for passengers [9].

To solve this problem, the article proposes a two-stage heuristic model called FRESET (Frequency Rationalization for Efficient Scheduling of Entire Transit). The model first calculates the base number of buses on routes, and then redistributes the remaining buses to routes based on load and demand indicators. The model is built in a way that is not algorithmically complex and is suitable for use by many transport agencies and is understandable.

The article demonstrates the practical results of this approach using the example of the transport network in the Republic of Karakalpakstan. Based on calculations, it was determined that the FRESET model can improve route loading by 20–30% and increase the overall quality of service.

2. Research methodology

The bus network in the Republic of Karakalpakstan consists of large and interconnected regional routes, with passenger traffic unevenly distributed at different times and across the region. This situation leads to overloading (congestion) on some routes, and inefficient bus traffic on others. The goal is to distribute the available buses (n=110) to routes in such a way that the distribution of buses to routes is balanced and no route is overcrowded.

Initial information

Direction	Daily demand (passenger)	Route length (km)	Bus capacity	Basic bus the number
R1	2500	12	50	7
R2	1800	10	50	5
R3	3200	15	50	9
R4	1400	8	50	4
R5	2000	11	50	6
Total	10,900			31

(“Baseline bus count” refers to the minimum number of buses needed to cover demand on each route)

2.1. Basic allocation step

The number of base buses needed to cover the daily demand on the routes was calculated using the following formula:

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[b] https://orcid.org/0000-0001-6479-6173

$$f_i = \left\lceil \frac{D_i}{C * N_i} \right\rceil$$

Here:

f_i- number of buses needed to cover the demand for route i,

D_i - daily passenger demand for route i (based on OD data),

C - capacity of one bus (number of passengers),

N_i- number of daily trips of the bus for route i (in the model, one bus makes 5 trips per day),

$\lceil * \rceil$- integer increasing function

Basic distribution step for route R1:

$$f_{R1} = \left\lceil \frac{2500}{50 * 5} \right\rceil = \left\lceil \frac{2500}{250} \right\rceil = 10$$

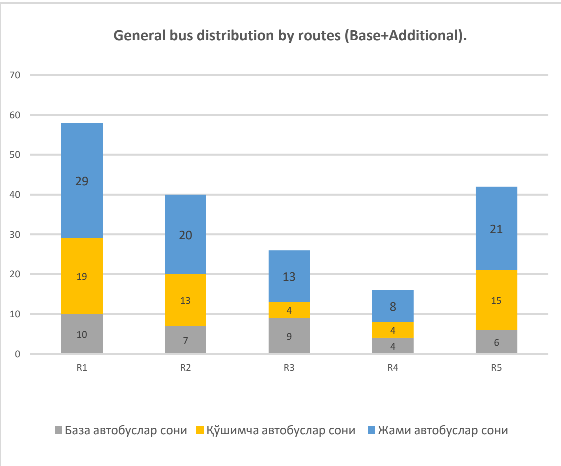

Figure 1. General bus distribution by routes (Base+Additional)

If a bus makes 5 trips per day, N_i=5, and the formula is adjusted accordingly. In this study, a FRESET (Frequency Rationalization for Efficient Scheduling of Entire Transit) model is proposed to rationally distribute buses across the urban transport network. This model was implemented in two stages:

2.2. Additional bus redistribution phase.

After 31 base buses, the remaining 110−31=79 buses are redistributed across the network. This allocation is made in proportion to the demand and load level on the route.

$$e_i = \left\lceil \frac{D_i}{\sum D_i} * E \right\rceil$$

e_i- the number of excess buses allocated to the i-th route,

$\sum D_i$- total passenger demand on all routes,

E- number of additional buses (vacant),

Stage of redistributing additional buses

For Route R1:

$$e_{R1} = \left\lceil \frac{2500}{10{,}900} * 79 \right\rceil = 19$$

Thus, according to calculations made taking into account the demand and load level on the routes, 10 base buses were determined as necessary at the previous stage to cover the daily demand of 2,500 passengers for the R1 route; in addition, as a result of the proportional distribution of a total of 79 excess buses based on the FRESET model, 19 additional buses were allocated to the R1 route, bringing the total number of operating buses to 29, creating the opportunity to cover the high passenger flow with stable and efficient service.

3. Results

Within the framework of this study, the redistribution of 110 existing buses along routes was implemented in the bus network of the Republic of Karakalpakstan, based on the FRESET (Frequency Rationalization for Efficient Scheduling of Entire Transit) model. The aim was to meet passenger demand, balance the load, and improve the efficiency of service quality.

First and foremost, 31 buses were allocated as a "base distribution" to meet the minimum requirements for each route based on daily demand. The remaining 79 buses were redistributed proportionally according to passenger flow, route length, and occupancy levels. Specifically, for the R1 route, considering the daily demand of 2,500 passengers, 10 base buses were allocated, and an additional 19 buses were redistributed according to the model, bringing the total number of buses to 29. This decision aims to improve service quality by reducing congestion on this route and increasing trip frequency, as shown in Figure 1. For the R3 route, which recorded the highest occupancy, a total of 13 buses were allocated, including 4 from the redistribution. This allows for effectively reducing the load on this route and preparing for future growth in passenger demand. Similarly, due to high demand on the R5 route, 6 base and 15 additional buses were allocated, totaling 21 buses.

The advantage of the FRESET model is that it enables optimization of resource allocation in a complex transport system through a simple, calculation-based approach, relying on local conditions and data. This, in turn, allows for the optimization of operational costs, reduction of traffic congestion, and ensures the stability of public transport services provided to the population.

4. Conclusion

This study demonstrated the potential to enhance public transport efficiency in the Republic of Karakalpakstan by redistributing existing vehicles in the bus network according to demand and passenger load levels. A two-stage approach, developed based on the FRESET (Frequency Rationalization for Efficient Scheduling of Entire Transit) model - comprising basic distribution and redistribution of surplus buses - balanced the load across routes and ensured equitable resource allocation in service provision. Out of a total of 110 buses, 31 were allocated as a basic distribution to meet the minimum demand on routes, while the remaining 79 buses were distributed proportionally to passenger flow. For instance, the high-demand R1 route was assigned 29 buses in total, consisting of 10 base buses plus an additional 19 buses to accommodate the increased passenger volume.

This served to stabilize transport services on this route and reduce waiting times. Additionally, due to high demand on the R5 route, a total of 21 buses were allocated, bringing the quality of service to an optimal level. In the research process, the use of a practical and modular approach based on precise calculations, instead of complex mathematical modeling, increased the applicability of the model in real-world conditions. This approach has proven to be one of the most effective solutions not only for the rational use of available resources but also for optimizing operational costs, reducing traffic congestion, and providing high-quality transport services to the population.

In the future, the model can be further improved by enriching it with parameters such as real-time passenger flow, changes in demand throughout the day, strategic importance of transport interchange points, and route significance. This enhancement expands the possibilities for implementing the model at a regional scale and in other cities.

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