https://doi.org/10.30932/1992-3252-2019-17-4-182-195

Cluster Analysis of the Routes of the New Management Model for Surface Urban Passenger Mass Transit



Maxim A. KUDRYASHOV **Radion S. AYRIEV** **Georgiy M. OVNANYAN**

Kudryashov, Maxim A., *State Unitary Enterprise Mosgortrans, Moscow, Russia.*
Ayriev, Radion S., *State Unitary Enterprise Mosgortrans, Moscow, Russia.*
Ovnanyan, Georgiy M., *Moscow Automobile and Road Construction State Technical University (MADI), Moscow, Russia*.*

ABSTRACT

The city of Moscow has implemented a new management model for surface urban passenger transportation (NMM). To consistently monitor the quality of transportation services it is suggested to introduce a methodology of its assessment.

The methodology for assessing quality of public transport services is supposed to be tested on routes serviced by commercial enterprises under state contracts for provision of public transportation services by public transport on the routes of regular passenger and baggage transportation by road in urban traffic.

The objective of the research was to select objects in order to test the methodology for assessing quality of public transportation services provided by surface urban public mass transit (SUPMT) on routes serviced in the framework of NMM.

A scientifically substantiated partition of a given sample of routes has been performed. The routes have been classified using the classical method of hierarchical cluster analysis, where the Euclidean distance with a single rule of cluster joining was used as a measure of proximity. The clustering procedure was performed using the Ward method.

Based on the results of the cluster analysis, ten routes were selected that are subject to further analysis.

Keywords: urban transport, management, new management model for surface urban mass transit, cluster analysis.

---

*Information about the authors:
Kudryashov, Maxim A. – head of the sector of human resources service of State Unitary Enterprise Mosgortrans, Moscow, Russia, sparky5@yandex.ru.
Ayriev, Radion S. – advisor to deputy director general of State Unitary Enterprise Mosgortrans, Moscow, Russia, ayrievrs@mail.ru.
Ovnanyan, Georgiy M. – Master's student at the department of road transportation of Moscow Automobile and Road Construction State Technical University (MADI), Moscow, Russia, georgy.ovnanyan@mail.ru.

Article received 06.12.2018, accepted 25.04.2019.

For the original Russian text please see p. 182.

New management model for surface urban mass transit

The system of urban passenger transport is the most important social sphere of the city of Moscow. Quality of life of the population and productivity of various sectors of the economy depend on effectiveness of its functioning. Improving the system of transport services for the population requires implementation of comprehensive research on assessment, analysis and identification of urgent problems of organizing transportation of passengers and baggage in the city of Moscow [1, pp. 1–9; 2, pp. 1–14].

With the growth of motorization and of the number of individual trips in the city of Moscow, the requirements for improving quality of public transportation services are being imposed on the public passenger transportation system.

The work of public transport must comply with all regulatory requirements to ensure safety of the environment, road traffic, and passenger transportation.

Based on the analysis of the current state of the urban passenger transport system in Moscow, previous research and best practices in development of transport systems of world cities, the Department of transport and development of road transport infrastructure of Moscow is developing a number of measures, implementation of which will significantly improve quality and safety of mass transit in Moscow.

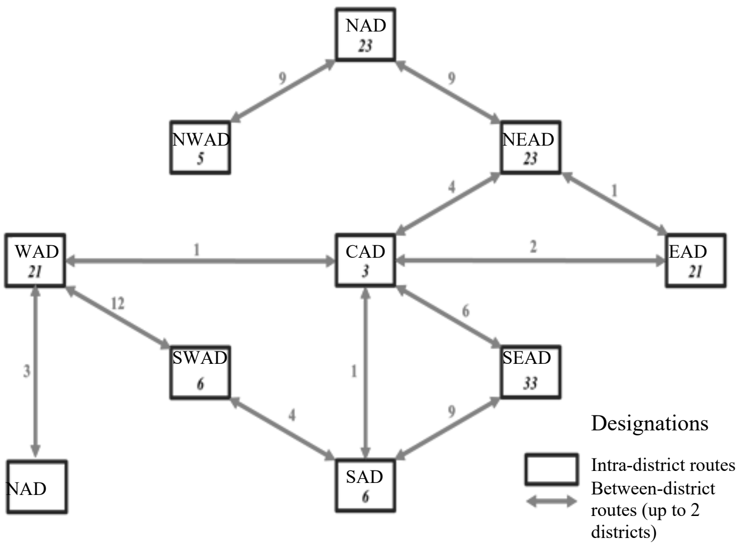
The most important direction for improving quality of public transport services provided in the sphere of surface urban public mass transit (SUPMT) is the transition in the city of Moscow to a new model of SUPMT management (NMM SUPMT), which provides for provision of transport services for the population on municipal routes of regular transportation of passengers and baggage under state contracts.

NMM SUPMT provides for integration of private motor transport enterprises into the public transport system of the city of Moscow with the transition to uniform standards for provision of transport services to the population.

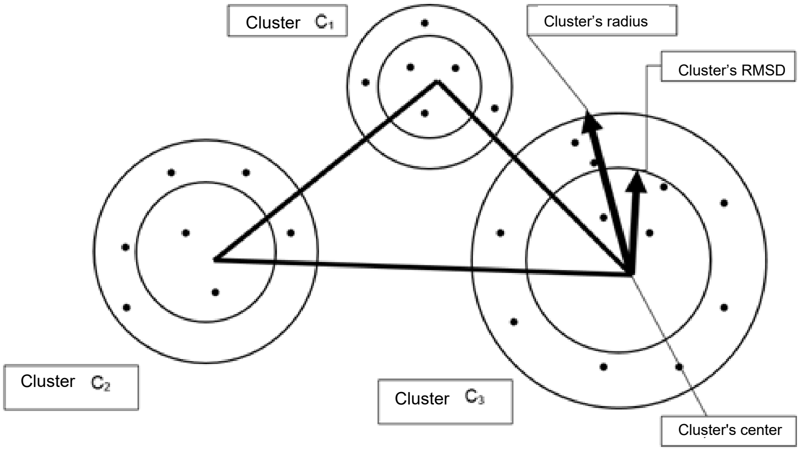
The admission of commercial motor transport enterprises to work on regular transportation routes in urban traffic was carried out on the basis of state contracts for public transport services based on the results of open tenders.

With the transition to NMM SUPMT, a new route network was developed and implemented taking into account elimination of duplicate routes, reducing congestion of the transport network, reducing traffic intervals and then adjusting the timetable. For each route, the optimal class of rolling stock was selected.

According to the requirements of [3, Appendix 1, p. 1] the fleet must comply with an ecological class of at least Euro-4, be adapted for transportation of low-mobility groups of people, equipped with air conditioning, heating systems, route indicators and information displays, airborne navigation and communication terminals, radio stations, video surveillance systems, etc.



Pic. 1. Graph of itineraries of the routes.



Pic. 2. Mathematical characteristics of the cluster.

Quality control of provision of transport services is carried out in the automatic mode of monitoring the operation of the fleet on the line regarding compliance with the itinerary of the route, schedule, compliance of the type of vehicles with the parameters of transportation, cleanliness of the passenger compartment, operability of the ramp for people with limited mobility, use of a single ticket, compliance with speed mode, etc.

The level of quality of transport services provided to the population by private carriers should not be lower than on the routes served by a public carrier.

In total, 211 routes within 63 lots were suggested for tender, the winners of which were eight private carrier companies that concluded state contracts for transport services for a period of 5 years [3].

The main motor transport company serving routes under state contracts is LLC Transautoliz, which is part of Autoline group of companies.

The performed analysis of transportation parameters [3, Appendix 3] and the Register [4] regarding the routes within NMM SUPMT in the context of districts showed that: 141 routes serve 1 district, 61 routes serve 2 adjacent districts (Pic. 1) and 9 routes serve 3 or more districts of the city of Moscow. The greatest number of intra-district routes goes through SEAD [Southeast administrative district] (33 routes), the smallest – in CAD [Central administrative district] (3 routes). The total length of the routes is more than 3600 km [3, 4]. At the same time, 43 % of the routes are served by small class buses.

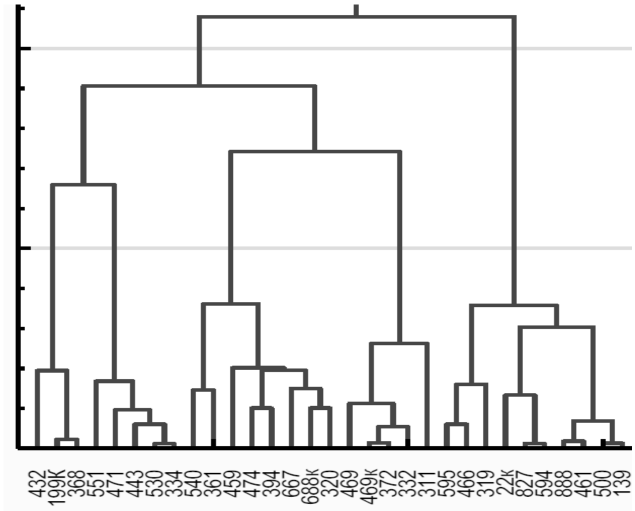
Justification and selection of the object of study

The *objective* of the study is selection of objects in order to test the methodology for assessing quality of public transport services for surface urban public mass transit on routes served by the new management model for surface urban mass transit.

It is proposed that the *methodology* for assessing quality of public transport services in accordance with the Standard [5, 6] should be applied on routes served by commercial enterprises under state contracts for provision of services for the population by public road transport on the routes of regular passenger and baggage transportation in city traffic.

In order to test the methodology for assessing the achieved level of quality of public transport services according to [5, 6], it is proposed to carry out a scientifically sound partition of a given sample of routes G, served as part of NMM SUPMT, into disjoint subsets $Q_1, Q_2, ..., Q_m$, according to the given criteria X_i so that each G_j route belongs to only one subset of the partition and that the routes belonging to the same subset are similar, while the routes belonging to different clusters are of different family, and then the route of each formed group could be selected.

For the purposes of this study, the use of the cluster analysis method is proposed. The advantage of this method, which distinguishes it from most mathematical and statistical methods, is the absence of restrictions on the type of objects under consideration and the possibility of considering a variety of source data [7, p. 7].



Pic. 3. A fragment of dendogram of cluster analysis.

Results of cluster analysis

The mathematical characteristics of the cluster are presented in Pic. 2.

Cluster's center is geometric mean of the points in the space of variables. Cluster's radius is maximum distance of points from cluster's center. The cluster size can be determined either by cluster's radius, or by root mean square deviation (RMSD) of objects for this cluster. An object belongs to a cluster if the distance from the object to the cluster's center is less than the cluster's radius [7].

To solve the problem of cluster analysis, it is necessary to define the concept of similarity and heterogeneity. The *i*-th and *j*-th routes fall into one cluster when the distance between points X_i and X_j is quite small, and fall into different clusters when this distance is sufficiently large. Thus, getting into one or different clusters is determined by the concept of the distance between X_i and X_j. The criterion for determining similarity and difference of clusters is the distance between the points on the scattering diagram.

The criterion for optimizing partition and determining the optimal number of clusters is the intragroup sum of squared deviations:

$$E = S_n = \sum_{j=1}^{n}\left(x_j - \bar{x}\right)^2 = \sum_{j=1}^{n} x_j^2 - \frac{1}{n}\left(\sum_{j=1}^{n} x_j\right)^2, \qquad (1)$$

where x_j – pair correlation coefficient.

Thus, the grouping process should correspond to a sequential minimum increase in the value of the criterion.

In case of heterogeneity of the units of measurement of parameters and the consequent impossibility of a reasonable expression of values on one scale, the task of normalizing the initial values of the selected parameters arises. Here are the main ways to normalize the parameters (the transition from the original values *X* to normalized *Z*):

$$Z = \frac{(x - \bar{x})}{\sigma}; \; Z = \frac{x}{\bar{x}}; \; Z = \frac{x}{x'};$$

$$Z = \frac{x}{x_{max}}; \; Z = \frac{(x - \bar{x})}{x_{max} - x_{min}}, \qquad (2)$$

where *Z* is normalized value of the parameter *x*;

$x - \bar{x}$ – average value of the parameter *x*;

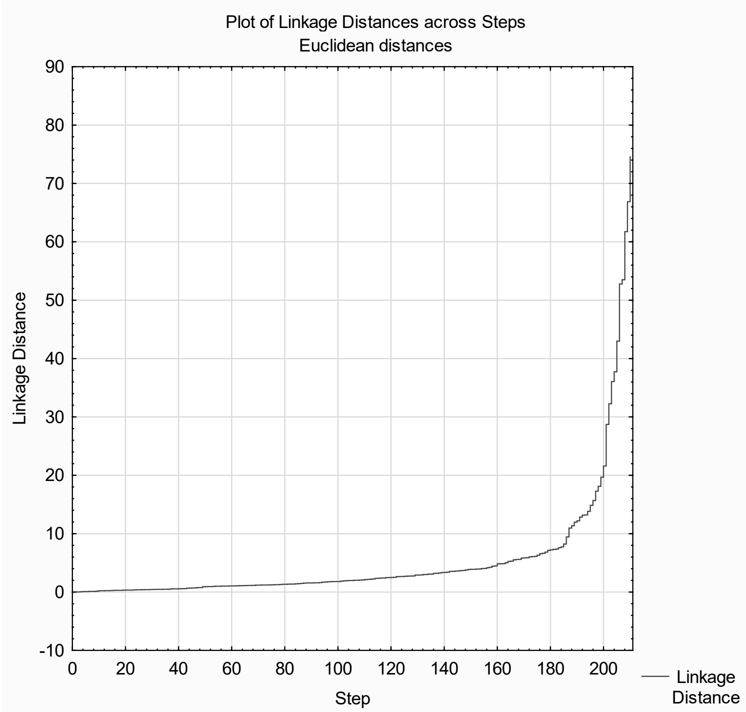
σ – root mean square deviation;

x' – normative (reference) value of *x;*

x_{max}, x_{min} are respectively maximum and minimum value of the parameter x.

Along with standardization of variables, there is the option of giving each of them a certain coefficient of importance, or weight, which would reflect the significance of the corresponding variable. One of the most scientifically substantiated methods for obtaining expert estimates is the method of independent multivariate examination [8–12].

It is proposed to classify routes using the classical method of hierarchical cluster analysis, where the Euclidean distance with a single rule of cluster joining will be used as a measure of proximity. The clustering procedure



Pic. 4. The process of combining routes into clusters.

was performed using the Ward's method [7, p. 19].

Clustering is proposed to meet the parameters that follow:

1. The districts through which the route goes in forward and reverse directions. This parameter of the route's belonging to a certain district corresponds to the value «1», or to value «0» otherwise.

2. The total length of the route, defined as the sum of the lengths of routes in forward and reverse directions.

3. The number of vehicles used for transportation.

4. The class of vehicles.

5. Transportation operator.

Heterogeneity of the units of measure and the consequent impossibility of a reasonable expression of the values of various indicators on one scale pose the task of normalizing the initial values of the selected criteria, that is, the expression that through the ratio of these values to a certain value reflects certain properties of this criterion.

Normalization of data of each parameter is performed by dividing the centered value by the root mean square deviation of the parameter.

A centered quantity that corresponds to a certain parameter means deviation (difference) between a random variable and its mathematical expectation.

It is worth noting that this normalization method involves recognition of all parameters as equivalent in terms of clarifying similarity of the objects under consideration. The results of hierarchical classification are presented in the form of a vertical dendrogram (Pic. 3), where the abscissa axis contains the values of the route numbers, and the ordinate axis – the Euclidean distance.

To determine the number of clusters to be further analyzed, it is necessary to choose a threshold distance, followed by determining

Table 1

The composition of clusters allocated by the Ward method

Cluster's number	Number of routes in the cluster
1	31
2	28
3	15
4	17
5	18
6	32
7	13
8	14
9	4
10	39

Pic. 5. The layout of the routes.

Table 2

Parameters of the routes under study

No. of the cluster	No. of the route	Name of the route
1	311	platform [rail station] Ostankino–m. [metro station] «Partisanskaya»
2	350	m. Tekstilshchiki–7th microdistrict of Maryinsky Park
3	99	138th quar. Vykhina–Avtozavodsky bridge (m. «Avtozavodskaya»)
4	141	st. Molostovykh–m. «Semenovskaya»
5	19	m. «Timiryazevskaya»–m. «Timiryazevskaya»
6	282	m. «Voikovskaya»–Korneichuk st.
7	63	Lobnenskaya st.–Lobnenskaya st.
8	456	8th microdistrict Mitina–8th microdistrict Mitina
9	550	m. «Rasskazovka»–platf. Peredelkino
10	553	m. «Leninsky prospect»–m. «Teply Stan»

the number of intersections with the branches of the dendrogram. The number of clusters was selected based on the analysis of the schedule of the process of combining routes (Pic. 4) and a table of steps for combining objects. The abscissa axis contains step number values, and the ordinate axis contains Euclidean distance.

The analysis of the merger schedule involves (Pic. 4) determining the «fracture» point and step number *m* at which the fracture occurs, with the subsequent determination of the number of clusters equal to *n-m*, where *n* is the number of routes in the cluster.

In addition, the table of steps for combining routes was analyzed and such a number of step *m* was found that merged at a significantly greater distance than at step *m-1*, followed by determining the number of clusters equal to *n—m*, where *n* is the number of routes in the cluster.

According to the results of the analysis, it was found that the fracture point is step 201, therefore, the number of clusters to be further analyzed is 211—201 = 10, with subsequent selection of any route from the formed cluster groups (Table 1).

Conclusion.

For further research purposes, a route per each cluster was selected (Table 2). The routes to be analyzed are shown in Pic. 5.

Further research is focused on testing the methodology for assessing the achieved level of quality of transport services [5, 6] on the selected routes of NMM SUPMT taking into account the previously performed analysis and evaluating its adaptability [12].

REFFERENCES

1. Bludyan, N. O., Roshchin, A. I., Antonov, M. N. On the issue of minimum social standards for public transport services [*K voprosu minimalnykh sotsialnykh standartov transportnogo obsluzhivaniya naseleniya*]. Deposited manuscript No. 754-B2009 30.11.2009.

2. Bludyan, N. O., Roshchin, A. I., Antonov, M. N. Assessment of criteria and standards for provision of regular passenger transportation by road [*Otsenka kriteriev i normativov obespechennosti regulyarnymi passazhirskimi perevozkami na avtomobilnom transporte*]. Deposited manuscript No. 753-B2009 30.11.2009.

3. The draft State contract for provision of public transport services by public transport on the routes of regular passenger and baggage transportation by road in urban traffic [*Proekt Gosudarstvennogo kontrakta na okazanie uslug po obespecheniyu transportnogo obsluzhivaniya naseleniya avtomobilnym transportom obshchego polzovaniya na marshrutakh regulyarnykh perevozok passazhirov i bagazha avtomobilnym transportom v gorodskom soobshchenii*]. [Electronic resource]: http://zakupki.gov.ru/44fz/filestore/public/1.0/download/priz/file.html?uid=011D6050DCE3418DA4370D88A4D898A3. Last accessed 24.12.2018.

4. Order of the Department of transport and development of road transport infrastructure of Moscow dated December 30, 2015 No. 61-02-504 / 5 (as amended on March 28, 2018) «On the register of routes for regular transportation of passengers and baggage by road and land electric transport in urban traffic (municipal scheduled routes)» [*Prikaz Departamenta transporta i razvitiya dorozhno-transportnoi infrastruktury g. Moskvy ot 30.12.2015 № 61-02-504/5 (red. ot 28.03.2018) «O Reestre marshrutov regulyarnykh perevozok passazhirov i bagazha avtomobilnym i nazemnym elektrichekim transportom v gorodskom soobshchenii (minitsipalnykh marshrutov regulyarnykh perevozok)»*]. [Electronic resource]: http://www.consultant.ru/cons/cgi/online.cgi?req=doc; base=MLAW; n=189578#03879497454759801 6. Last accessed 24.12.2018.

5. Decree of the Ministry of Transport of Russia dated 01.31.2017 No. NA-19-r «On approval of the social standard of public transport services for transportation of passengers and baggage by road and urban land electric transport» [*Rasporyazhenie Mintransa Rossii ot 31.01.2017 № NA-19-r «Ob utverzhdenii sotsialnogo standarta transportnogo obsluzhivaniya naseleniya pri osushchestvlenii perevozok passazhirov i bagazha avtomobilnym transportom i gorodskim nazemnym elektricheskim transportom»*]. [Electronic resource]: https://special.mintrans.ru/upload/iblock/736/rasp_mt_na_19r_31012017.pdf. Last accessed 05.11.2018.

6. Decree of the Ministry of Transport of the Russian Federation dated April 13, 2018 No. NA-55-r «On amendments to the social standard of the public transport services for transportation of passengers and baggage by road and urban electric land transport, approved by Decree of the Ministry of Transport of the Russian Federation of 31 January 2017 No. NA-19-r [*Rasporyazhenie Ministerstva transporta RF ot 13 aprelya 2018 № NA-55-r «O vnesenii izmenenii v sotsialniy standart transportnogo obsluzhivaniya naseleniya pri osushchestvlenii perevozok passazhirov i bagazha avtomobilnym transportom i goroskim nazemnym elektricheskim transportom, utverzhdenniy rasporyazheniem Ministerstva transporta Rossiiskoi Federatsii ot 31 yanvarya 2017* г. *№ NA-19-r»*]. [Electronic resource]: http://www.garant.ru/products/ipo/prime/doc/71837354/#ixzz5W5Ft8hwK. Last accessed 05.11.2018.

7. Bureeva, N. N. Multivariate statistical analysis using STATISTICA IFR. Educational material on the continuing education program «Application of software in scientific research and teaching mathematics and mechanics» [*Mnogomerniy statisticheskiy analiz s ispolzovaniem PPP «STATISTICA». Uchebno-metodicheskiy material po programme povysheniya kvalifikatsii «Primenenie programmnykh sredstv v nauchnykh issledovaniyakh i prepodavanii matematiki i mekhaniki»*].

8. Bludyan, N. O., Moroz, D. G., Shestopalov, N. Yu. Evaluation and selection of vehicle type for taxi transportation [*Otsenka i vybor tipa transportnogo sredstva dlya taksomotornykh perevozok*]. *Vestnik Moskovskogo avtomobilno-dorozhnogo gosudarstvennogo tekhnicheskogo universiteta (MADI)*, 2018, Iss. 3, pp. 115—121.

9. Bludyan, N. O., Akhokhov, A. A., Dorofeyuk, Yu. A., Chernyavsky, A. L. Independent multivariate expertise in the task of managing inter-regional bus transportation [*Nezavisimaya mnogovariantnaya ekspertiza v zadache upravleniya mezhregionalnymi avtobusnymi perevozkami*]. *Large systems management: collection of works*, 2013, Iss. 46, pp. 163—178.

10. Bludyan, N. O., Akhokhov, A. A., Dorofeyuk, Yu. A., Chernyavsky, A. L. Methods of collective multivariate expertise in the task of regulating the market for inter-regional bus transportation [*Metody kollektivnoi mnogovariantnoi ekspertizy v zadache regulirovaniya rynka mezhregionalnykh avtobusnykh perevozok*]. *Innovatsii i investitsii*, 2013, Iss. 4, pp. 214—217.

11. Bludyan, N. O., Akhokhov, A. A., Dorofeyuk, Yu. A., Chernyavsky, A. L. Development of a control system for inter-regional bus transportation based on the methods of collective multivariate examination [*Razrabotka sistemy upravleniya mezhregionalnymi avtobusnymi perevozkami na baze metodov kollektivnoi mnogovariantnoi ekspertizy*]. *Problemy upravleniya*, 2013, Iss. 4, pp. 29—38.

12. Ayriev, R. S., Kudryasov, M. A. Quality indices of public transportation services. *World of Transport and Transportation*, Vol. 16, 2018, Iss. 4, pp. 140—149. ●