



Analysis of Methodological Approaches to the Selection of Regular Municipal Routes to be Served by Electric Buses



Maxim A. KUDRYASHOV



Maxim V. SKORKIN

Maxim A. Kudryashov¹, Maxim V. Skorkin²

^{1, 2} Moscow Automobile and Road Construction State Technical University (MADI), Moscow, Russia.

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✉ ¹ sparky5@yandex.ru.

ABSTRACT

The article is devoted to the analysis of trends of operation and the selection of parameters for solving the problem of optimal allocation of electric buses to serve a given set of routes.

The number of registrations and sales is estimated as one of the methods for assessing the trends in operation of electric buses. The average values of the battery capacity are determined depending on the category and purpose of operation of an electric bus. The analysis of governmental programs for electrification of passenger transportation of some countries has resulted in compiling a set of statistical values, followed by the study of domestic experience in operating electric buses on regular municipal routes.

The results of the analysis, considering the identified trends, have allowed setting the objective of selecting priority parameters for determining the routes to be served with electric buses.

Regular municipal routes served by the Mosgortrans, largest European operator of electric buses, have been selected as the object of the study.

The main research method has been based on PRISMA, a proved methodology of meta-analysis of previously completed studies. The analysis of 22 methodological approaches to organising the operation of electric buses has resulted in identifying four priority technical and operational parameters influencing the selection of the route (L_m , V_e , N_{stop} , Q). The study has allowed to suggest a general algorithm for solving the problem of selecting optimal regular municipal routes for operation of electric buses and to identify directions for further research.

Keywords: passenger transport, electric bus, regular municipal routes, technical and operational indices of a route.

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BACKGROUND

The operation of electric buses on regular municipal routes has recently become an intensively implemented trend. Thus, relevant is solving the problem of optimal placement of electric buses to serve a given set of routes. The *objective* of the study described in the article is to analyse operating trends and the selection of parameters for solving the above problem.

RESULTS

Analysis of Global Trends in Operation of Electric Buses on Regular Municipal Routes

One of the methods for assessing trends in the operation of electric buses is to estimate the number of registrations and sales. Registrations show the number of vehicles that were first registered with government agencies or insurance companies.

Pic. 1 shows the results of the analysis of the number of registrations and the percentage of sales of electric buses in the world in 2016–2022. It should be noted that in China, vehicle insurance is issued for the vehicle, not for a specific driver.

As the report of the International Energy Agency (IEA) shows, «in 2022, nearly 66 000 electric buses... were sold worldwide, representing about 4.5 % of all bus sales... worldwide. China continues to dominate production and sales of electric... buses. In 2022, 54 000 new electric buses... were sold in China, representing 18 %... of total sales in China and about 80 %... of global sales...». It's worth noting that «...many of the buses... being sold in Latin America, North America and Europe are Chinese brands»¹.

«Within Europe, the sales share for electric buses was highest in Finland, where electric buses made up two-thirds of sales in 2022, Norway and the Netherlands, where they made up nearly half of sales, and Denmark, where they made up nearly one-third. Sales shares were also high in Sweden, Switzerland and Israel»¹.

It is important to note that the production and sales of electric buses have fluctuated over few years due to the subsidies provided (the total amount of subsidies from 2018 to 2021 was less than 2,9 billion USD), but since 2021, sales of electric buses have begun to grow again¹.

Of the electric bus models available for sale in 2022, 60 % (more than 500 models) were

produced by Chinese manufacturers. Another 20 % (more than 170 models) were produced by American manufacturers and 15 % (more than 120 models) by European manufacturers¹.

A table compiled based on data¹ and the Global Drive to Zero ZETI database² shows model range of zero-emission buses and their average battery capacity (Table 1).

Automotive lithium-ion (Li-ion) battery demand increased by about 65 % to 550 GWh in 2022, from about 330 GWh in 2021, primarily as a result of growth in electric passenger car sales, with new registrations increasing by 55 % in 2022 relative to 2021¹.

In 2022, according to the findings of IEA global-ev-outlook-2023 report, venture capital investments «in start-ups producing vehicles and charging technologies increased by 50 % to USD1,2 billion. The increase was particularly high in the charging segment, which saw an all-time high among early-stage funding at USD730 million. There was also a notable increase in funding for battery recycling and reuse, which stood at USD200 million, an eightfold increase relative to 2021»¹. The similar trend was revealed by Cleantech Group i3³.

Based on the database of the International Energy Agency (IEA)⁴ the authors selected 294 policies (including programs, strategic plans, grants, permitting regimes, etc.) referring to electrification of the urban passenger land transport, among which most had been approved in Spain, Portugal, the USA, China, Italy, and Canada (Pic. 2).

Of 294 policies, 223 (76 %) were in force, 66 (23 %) had ended or achieved, and the remaining were announced (at the approval or development stage) at that time (Pic. 3).

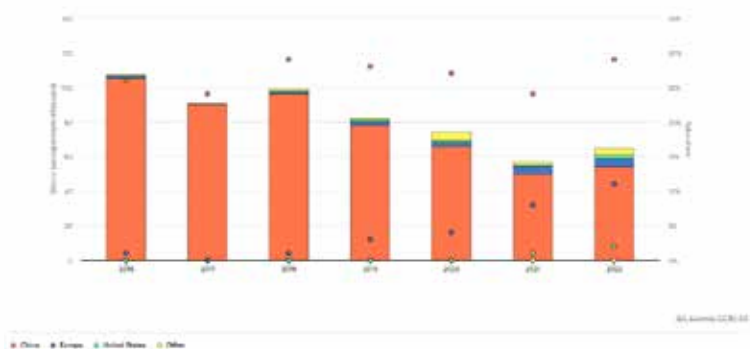
An analysis of the jurisdiction of the policies (Pic. 4) showed that they were predominantly within national jurisdiction (239 policies or 81,3 % of total), followed by policies within city/municipal jurisdiction (30 or 10,2 %), within state/provincial jurisdiction (22 or 7,5 %) and international jurisdiction (3 or 1 %).

² ZETI (Zero-Emission Technology Inventory). [Electronic resource]: <https://globaldrivetozero.org/tools/zeti/>. Last accessed 04.12.2023.

³ Cleantech Group i3 database [Electronic resource]: <https://www.cleantechforeurope.com/publications/cleantech-q3-briefing-2022#chapter-03>. Last accessed 04.05.2023.

⁴ IEA policies database [Electronic resource]: <https://www.iea.org/policies?sector%5B0%5D=Passenger%20transport%20%28Road%29>. Last accessed 04.05.2023.

¹ Global EV Outlook 2023. The International Energy Agency [Electronic resource]: <https://www.iea.org/reports/global-ev-outlook-2023>. Last accessed 04.12.2023.

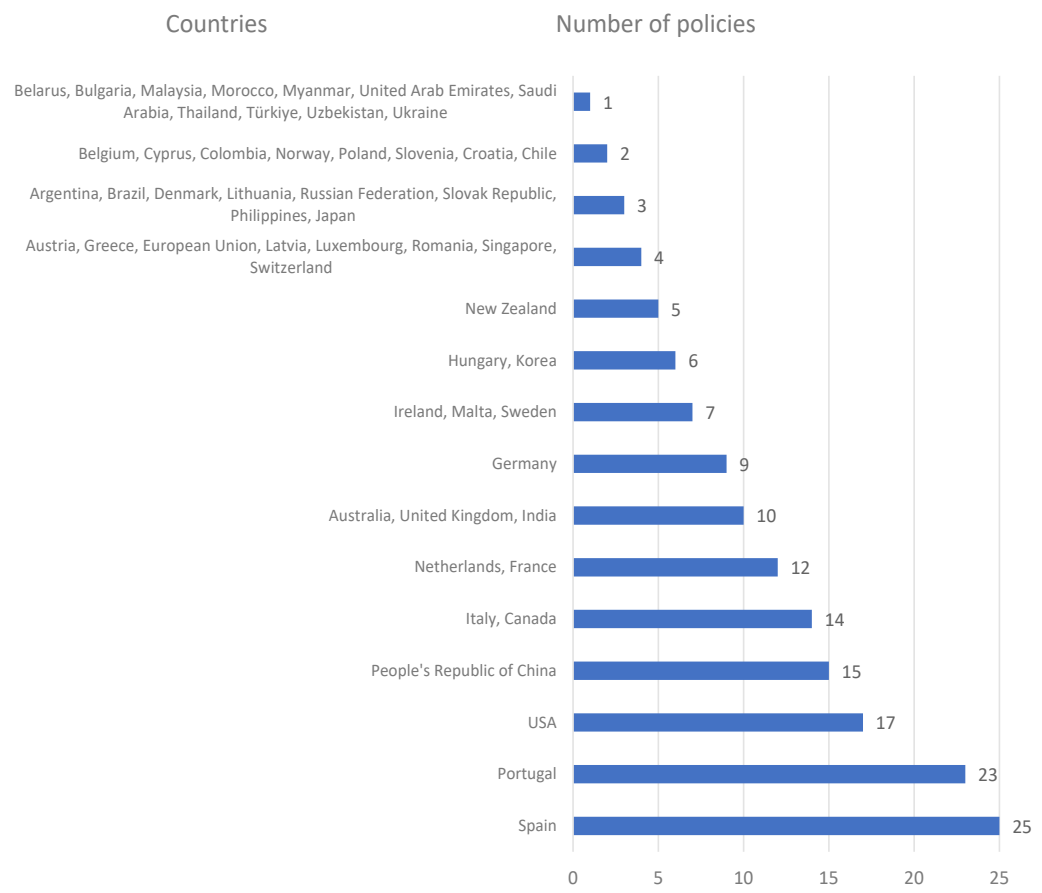


Pic. 1. Electric bus registrations and sales share by region, 2015–2022 [IEA (2023), Electric bus registrations and sales share by region, 2015–2022, IEA, Paris <https://www.iea.org/data-and-statistics/charts/electric-bus-registrations-and-sales-share-by-region-2015-2022>, Licence: CC BY 4.0].

Table 1

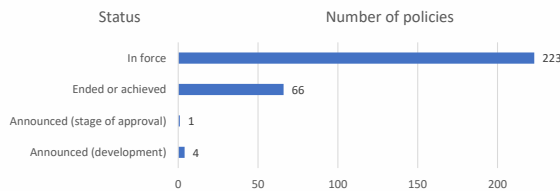
Average capacity of electric bus batteries [¹, Global Drive to Zero ZETI database]

Vehicle category and purpose	Average battery capacity (kWh)				Change in average indicator 2019–2022
	2019	2020	2021	2022	
M3III, transit bus	264	322	225	345	31 %
M3I, M3II, shuttle bus	104	119	120	150	45 %
M3I, M3II, school bus	155	141	207	137	–12 %

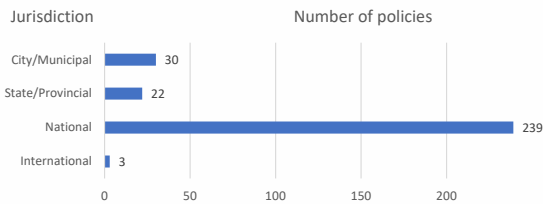


Pic. 2. Number of policies in the field of electrification of urban passenger land transport in different countries [based on the data ¹].





Pic. 3. Distribution of policies by status [based on the data *].



Pic. 4. Distribution of policies by jurisdiction [based on the data *].

Table 2

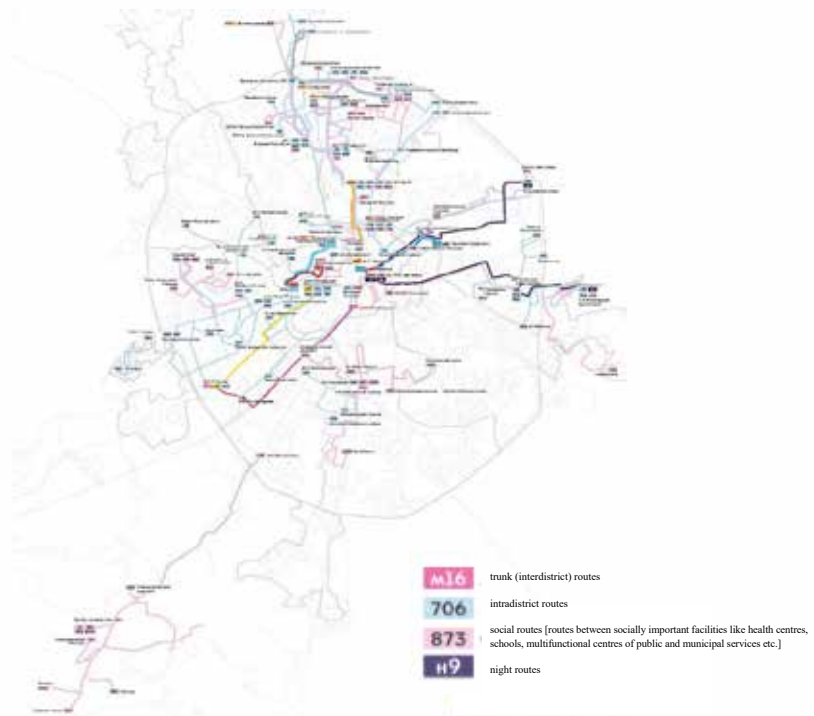
Model range of electric buses by manufacturers [compiled by the authors]

№	Manufacturer	Number of models
1	PJSC KAMAZ	2
2	PJSC GAZ	1
3	LLC Volgabus	1
4	JSC Sinara-Transport Machines	1
5	LLC PK Transport Systems	3
6	JSC Stroytrans	1

Table 3

Operation of electric buses on regular municipal routes [compiled by the authors]

City	Number of electric buses	Number of routes
Moscow	1055	79
St.Petersburg	10	1
Lipetsk	5	1
Vladivostok	2	1
Rybinsk	2	1
Sochi	2	1
Tyumen	1	1



Pic. 5. Electric bus route map (Electric buses' route map.

[Electronic resource]: <https://www.mosgortrans.ru/electrobus/map/>. Last accessed 07.05.2023.).

A significant number of analysed policies contains a forecast for the range and capacity of electric buses for the period up to 2030 under various scenarios as well as forecast values for the number of charging stations.

Russian Experience of Electric Buses’ Operation

As of 2023, the main manufacturers of electric buses in the Russian Federation were KAMAZ PJSC, GAZ PJSC, Volgabus LLC, Sinara-Transport Machines JSC, PC Transport Systems LLC, Stroytrans JSC. The model range presented on the official websites of the manufacturers is summarised in Table 2.

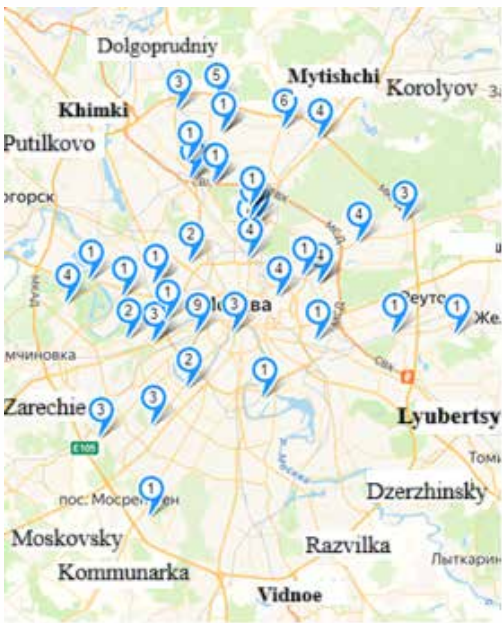
As of January 2023, electric buses served regular municipal routes in seven cities (Table 3).

Thus, the largest operator of urban passenger land transport system operating electric buses on regular municipal routes is Mosgortrans [literally Moscow Transport], state unitary enterprise. As of March 2023, Mosgortrans operated 1055 electric buses on 79 routes. The mapping of the routes served by electric buses is shown in Pic. 5.

The analysis of information on the charging infrastructure of electric buses (the number and location of charging stations) was carried out based on the results of concluded contracts published on the public procurement website. Based on the analysis, it was revealed that at the end of 2022, there were 208 charging stations in Moscow, some of which are shown in Pic. 6. The location of 82 charging stations was missing in the TORs (terms of reference) that read in those cases as «the exact delivery address is provided to the Supplier by official notification from Mosgortrans within 5 (five) working days from the date of signing the contract».

Analysis of Methodological Approaches to Assigning Electric Buses to a Route

To identify the factors influencing a conversion of a route to the use of electric buses or the creation of a new route for the electric buses, an analysis of possible methodological approaches to the operation of electric buses on municipal routes was conducted based on the previously tested PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology [1]. The general algorithm of the methodology is shown in Pic. 7.



Pic. 6. Location of some charging stations of the Mosgortrans [the picture compiled by the authors].

The list of search queries was formed using software products for compiling a semantic core and analysing keywords in previously completed studies.

An additional analysis of keywords in previously completed studies was performed during the subsequent assessment of frequency and clustering considering their semantics.

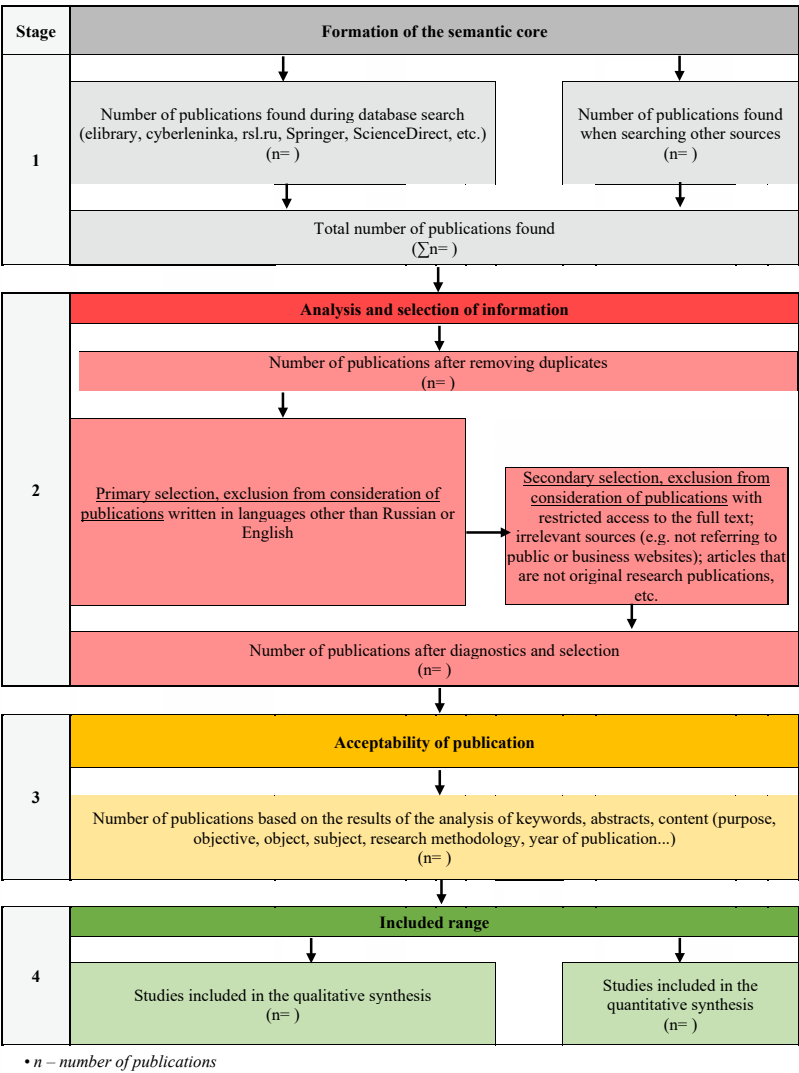
The analysis shows that this area has become especially relevant in recent years, and it should also be noted that most of the works was performed by the authors of different countries.

The analysis showed that the main indicators when choosing a route to be served by electric buses are passenger flow, speed, number of stopping points and route length. The time it takes for a bus to make a full round trip on the route is excluded from further analysis, since this parameter is directly dependent on the considered route length, speed, and number of stopping points. Table 4 presents the summary results of the qualitative analysis of the selected studies.

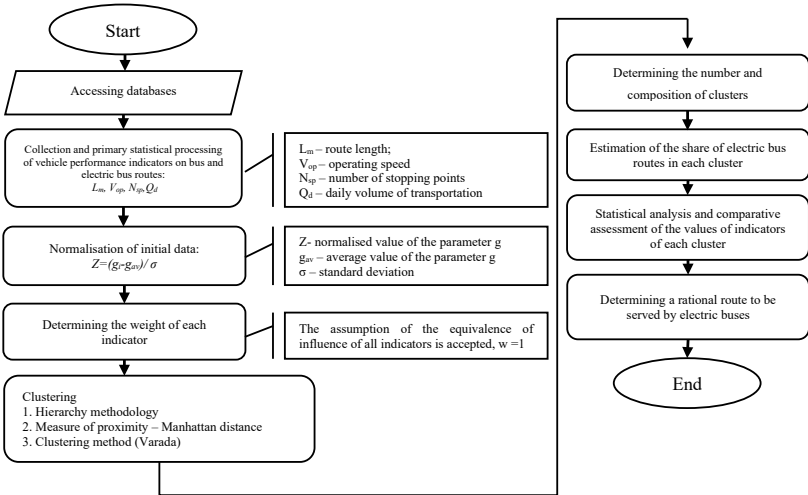
Rationale of Selection of a Bus Route Intended to Be Further Served by Electric Buses

When developing projects for the operation of electric buses on regular municipal routes, it is necessary to determine the qualitative and quantitative requirements for the charging infrastructure and the fleet and perform an economic assessment of the proposed





Pic. 7. Adapted PRISMA methodology scheme [developed by the authors].



Pic. 8. Algorithm for solving the problem of selecting optimal regular municipal routes to be served by electric buses [performed by the authors].

Table 4

Consideration of the indicators influencing the choice of a route [compiled by the authors]

№	Technical and economic indicators												Source
	Route							Passenger flow					
	V _{op}	I	L _r	t _{fit}	F _e	N _{sp}	l _j	Q _{max}	Q _h	Q _d	P _i	Q _{seg}	
1	+	-	+	+	+	+	+	+	+	+	+	+	[2]
2	+	-	+	+	+	+	+	+	+	+	+	+	[3]
3	+	-	+	+	+	+	+	+	+	+	+	+	[4]
4	+	-	+	-	+	+	+	+	+	+	-	+	[5]
5	+	+	+	+	+	+	-	-	+	+	-	-	[6]
6	+	+	+	+	-	-	+	+	+	+	-	-	[7]
7	+	-	+	+	+	+	-	-	-	+	-	-	*
8	+	-	+	+	+	-	+	-	-	+	-	-	[8]
9	+	-	+	+	-	+	+	-	-	-	-	-	[9]
10	+	+	+	+	-	+	+	+	-	-	-	-	[10]
11	-	-	+	+	-	+	+	-	+	+	-	-	[11]
12	+	-	+	+	-	+	-	-	-	-	-	-	[12]
13	-	-	+	+	-	+	+	-	-	-	-	-	[13]
14	+	-	+	-	-	+	+	-	-	-	-	-	[14]
15	-	-	+	-	-	+	+	-	-	-	-	-	[15]
16	-	-	+	+	-	-	+	-	-	+	-	-	**
18	-	-	+	+	-	-	-	-	+	+	-	-	[16]
19	-	-	+	+	-	-	-	-	-	-	-	-	***
20	+	+	+	+	-	-	-	-	-	-	-	-	[17]
21	-	-	+	+	+	+	-	-	-	-	-	-	[18]
22	-	-	+	-	-	-	-	-	-	-	-	-	[19]
Σ	13	4	21	17	8	14	13	6	8	11	3	4	

Notes: V_{op} – operating or service speed of vehicles on a route; I – time interval between two electric buses arriving at a stopping point, frequency of service; L_r – length of a route; t_{fit} – time it takes for an electric bus to make a full round trip in the route; F_e – electric bus service frequency; N_{sp} – number of stopping points; l_j – length of a j^{th} segment of a route; Q_{max} – maximum passenger flow; Q_h – hourly passenger flow; Q_d – daily passenger flow; P_i – total number of passengers embarking and disembarking at an i^{th} stopping point; Q_{seg} – passenger flow within route segments.

* Report of the International Association of Public Transport Union (UITP). Performance evaluation framework: For electric buses in India. [Electronic resource]: <https://www.uitp.org/publications/performance-evaluation-framework-for-electric-buses-in-india/>. Last accessed 05.05.2023.

** The Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. Training Needs Assessment for Electric Buses in India: Volume I–Identification of Training Needs. [Electronic resource]: <https://transformative-mobility.org/multimedia/training-needs-assessment-for-electric-buses-in-india-volume-i-identification-of-training-needs/>. Last accessed 05.05.2023.

*** E-Bus. Solution booklet. Smart Cities Marketplace 2023 European Union. [Electronic resource]: <https://www.eiturbanmobility.eu/wp-content/uploads/2023/02/230113-Solution-Booklet-E-bus-Updated.pdf>. Last accessed 07.05.2023.

solutions under the specific operating conditions.

The general algorithm for solving the problem of selecting optimal regular municipal routes to be converted for the operation of electric buses, considering the selected parameters, is shown in Pic. 8.

CONCLUSION

Further research should focus on statistical and cluster analysis of bus, electric bus routes, and the complete set of routes of Mosgortrans using the selected parameters with an assessment of the share of electric bus routes in the clusters. Additional assessment of the conformity of bus and electric bus routes could be proposed through comparing the average values of the standardised

indicators of the entire set of the resulting clusters of electric bus and bus routes. Based on the analysis results, a hypothesis can be put forward about the greatest conformity of a cluster of bus routes with electric bus routes. To test the proposed methodology and solve the technological problems of organising the operation of the fleet, considering the homogeneity of the route parameters in the cluster, a route is selected, and the main technological problems of organising the operation of an electric bus on the selected route are solved:

- determination of the nominal passenger capacity in accordance with the requirements of the social standard of public transport services as amended by the order of the Ministry of Transport of Russia dated 13.04.2018 No NA-55-r;



– planning the operation of the fleet of electric buses and drivers on the route, including traffic scheduling, and planning of energy consumption.

In conclusion, it is necessary to calculate the main technical, operational and economic indicators, draw up a daily statement of technical and economic performance, and estimate current costs under the standard taxation system.

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Information about the authors:

Kudryashov, Maxim A., Senior Lecturer at the Reference Department of Urban Passenger Transport operated in cooperation with the Mosgortrans, State Unitary Enterprise, Moscow Automobile and Road Construction State Technical University (MADI), Moscow, Russia, sparky5@yandex.ru.

Skorkin, Maxim V., Bachelor at the Department of Road Transport Moscow Automobile and Road Construction State Technical University (MADI), Moscow, Russia, xzelution@yandex.ru.

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