ORIGINAL ARTICLE
DOI: https://doi.org/10.30932/1992-3252-2022-20-4-8

World of Transport and Transportation, 2022, Vol. 20, Iss. 4 (101), pp. 240–246

Study of the Influence of Factors on Passenger Service Quality and Efficiency of Rolling Stock Use



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ABSTRACT

The tasks of transport planning are relevant for most countries and comprise implemenation of solutions at regional and local level. The development of transport planning documents in the constituent entities of the Russian Federation is an acute problem and implies the achievement of such goals as improving the quality of passenger transportation and reducing transportation costs. Each of the transport planning documents includes a list of measures, the implementation of which improves the quality of passenger service and the efficiency of the use of rolling stock.

The objective of the article is to determine the significance of the influence of technical and operational factors on the resulting indicators of passenger service quality and efficiency of rolling stock use. The research applied experiment planning method described in the work of Yu. P. Adler.

The experiment planning method used makes it possible to obtain quantitative estimates of the influence of factors with the same reliability as with other methods. The evaluation was carried out for independent or conditionally independent factors. In the researched case, such factors comprise the number of buses on the route, the length of the route, the turnaround time, the downtime at the terminal points, the allowable deviation from the schedule, the work hours of the drivers, the zero mileage of all buses.

Constants in the calculations are independent factors related to the characteristics of the demand for transportation, since when carrying out measures to improve the organisation of the work of buses on routes, they cannot be influenced. These factors comprise the walking distance on the route, the average travel distance of a passenger on the route and the passenger flow on the most loaded haul.

The method is implemented in the article on the example of an operating bus on the route. For all basic factors, the upper, lower, and main levels are set. Based on the analysis of the actual values of technical and operational indicators on the existing routes of Moscow region, the numerical values of the above levels were determined. Next, the variation intervals for each factor were selected. An experiment in which all possible combinations of factor levels are implemented is known as a full factorial experiment. The coefficients calculated from the results of the experiment indicate the strength of the influence of a factor. The value of the coefficient corresponds to the contribution of this factor to the value of the optimisation parameter when the factor moves from the zero level to the upper or lower one.

As a result of the research, it was found that five basic factors influence the time spent by a passenger, travel comfort, and the completeness of revenue collection, and ten factors affect the daily costs of servicing the route for a carrier. The specificity of the problem is that for all four optimisation parameters, one and the same matrix can be constructed. To conduct a full factorial experiment with varying ten factors at two levels, it is necessary to carry out more than a thousand calculation options. However, in accordance with the methodology, in this case, we can limit ourselves to the minimum number of calculations. On this basis, an experiment planning matrix was built, then, based on the results of calculations, the coefficients in the regression equations for each of the optimisation parameters can be determined. The regression coefficients obtained when calculating the experiment design matrix are similar to those that could be obtained as a result of calculations using the least squares method. Based on this, it is possible to calculate all the statistical characteristics of the basic factors necessary to determine the closeness of the relationship between the factors and optimisation parameters, as well as between the factors themselves.

The experiment planning method used in the study made it possible to identify the factors influencing each of the four optimisation parameters. Therefore, the explicit dependence of the optimisation parameters on such a factor as the number of buses on the route was confirmed, but at the same time, the factors were ranked according to the degree of their influence on the result. The correspondence of the obtained results to real and obvious dependencies has allowed to conclude that the chosen method and its implementation are correct.

Keywords: *urban passenger transport, passenger service quality, experiment planning.*

For citation: *Matantseva, O. Yu., Aredova, A. K., Shchegoleva, I. V. Study of the Influence of Factors on Passenger Service Quality and Efficiency of Rolling Stock Use. World of Transport and Transportation, 2022, Vol. 20, Iss. 4 (101), pp. 240–246. DOI: https://doi.org/10.30932/1992-3252-2022-20-4-8.*

The text of the article originally written in Russian is published in the first part of the issue.
Текст статьи на русском языке публикуется в первой части данного выпуска.

INTRODUCTION

Currently, the problem of developing transport planning documents in the constituent entities of the Russian Federation is quite relevant [1; 2]. The documents include models of organising transport services for the population, schemes for organising traffic and programs for development of transport infrastructure [3–5]. In addition, entities must develop a planning document for scheduled passenger transportation[1].

The main goals laid down in formation of the listed documents are [6; 7]:

• Improving the quality of passenger transportation.

• Reduction of transportation costs at a given level of transport service quality.

Each of the documents related to transport planning includes a list of measures for organisation and technology of passenger transportation.

The quality of passenger service and the efficiency of the use of rolling stock depends on certain options for the selected organisational and technological measures. This choice itself depends on numerous factors, and many of these factors simultaneously affect both the quality of service and the efficiency of the use of rolling stock. Some of the indicators cannot be quantified or their value does not depend on the carrier. For example, the cost paid by a passenger for a trip or safety of the driver [8–13].

As a method for determining the significance of the influence of factors on the resulting indicators, the experiment planning method described in the work of Yu. P. Adler [14] was used. This method makes it possible not only to reduce the number of calculation options, but also to obtain quantitative estimates of the influence of factors with the same reliability as with other methods.

RESULTS

Choice of Factors and Objective Functions

To carry out the analysis using the experiment planning method, all input factors were divided into dependent and independent ones, then, from the total number of input factors, factors that are not interdependent selected, or those that can be considered conditionally independent.

To assess the quality and efficiency of bus transportation, the following factors were analysed:

1. The number of buses on the route – X_1.
2. The length of the route – X_2.
3. Turnover time – X_3.
4. Downtime at the terminal points – X_4.
5. Permissible deviation from the schedule, set in accordance with regulatory documents – X_5.
6. The total time of work of drivers with a discontinuous schedule – X_6.
7. The total work time of drivers on the route per 24 hours – X_7.
8. Downtime hours – X_8.
9. Work hours on public holidays – X_9.
10. Night hours of work of all drivers on the route per day – X_{10}.
11. Zero mileage of all buses on the route per day – X_{11}.

Experiment planning is «a procedure for choosing the number and conditions for conducting experiments that are necessary and sufficient to solve the problem with the required accuracy» [4].

In this case, the values of four objective functions (optimisation parameters) were calculated: passenger's time consumption, the comfort of the trip, the completeness of the collection of revenue and the costs incurred by the passenger motor transport organisation (PATP). At the first stage of calculations, according to the experiment planning methodology, a linear dependence of each criterion indicator of efficiency and quality on the basic factors is assumed, i.e., an economic-statistical model is built in the form:

$$Y = a_1X_1 + a_2X_2 + ... + a_nX_n. \qquad (1)$$

To obtain the numerical values of the parameters of this model, it is necessary to build an experiment planning matrix to obtain the value of each of four optimisation parameters (passenger time (Y_T), travel comfort (Y_N), revenue collection completeness (Y_C) and the expenses of PATP as for the route per day (Y_E). The values of the basic factors are changed.

Factors are divided into quantitative and qualitative ones. Qualitative factors do not correspond to a numerical scale as for quantitative factors, however, it is possible to construct a conditional ordinal scale [4].

To carry out calculations using the experiment planning method, it is necessary to select from the total number of input factors those that are not dependent on each other, or those that can be considered conditionally independent in the calculations.

[1] Methodological recommendations for development of the Planning Document for regular transportation of passengers and luggage along municipal and intermunicipal routes by road transport and urban surface electric transport (approved by the Ministry of Transport of Russia on June 30, 2020). Decree of the Government of the Russian Federation of December 25, 2015, No. 1440 «On approval of requirements for programs for integrated development of the transport infrastructure of settlements, urban districts». Guidelines for development of transport planning documents for the constituent entities of the Russian Federation, approved by the Minutes of the meeting of the working group of the project committee for the national project «Safe and high-quality roads» dated August 12, 2019, No. IA-63.

Table 1

Dependence of traffic regularity on downtime at the terminal point [15]

Indicator name	Designation	Indicator value					
Idle time at the terminal point	T_{term}	0	1	2	3	4	5
Regularity	R	0,6	0,71	0,79	0,85	0,87	0,88

In this case, such factors are X_1, X_2, X_3[2], X_4, X_5, X_6, X_7, X_8, X_{10}, X_{11}.

Independent factors related to the characteristics of demand for transportation, such as (X_{22}) *lwd* (walking distance on the route), (X_{20}) l_{av} (average travel distance of a passenger on the route), (X_{21}) Q_m (passenger traffic on the most loaded haul) in the calculations are accepted as permanent, because when carrying out measures to improve the organisation of the work of buses on routes, an employee of the operational service cannot influence their value.

The remaining input factors are calculated using the following formulas:

1) Time on duty of all buses on the route T*d* (X_{12}):

$$T_d = A \cdot T_o, \qquad (2)$$

where A – the number of buses on the route;

T_o – average duration of operation of one bus on the route.

2) The actual number of trips on the route f_a (X_{13}):

$$f_a = T_d / T_{turn} \cdot 60, \qquad (3)$$

where T_{turn} – turnaround time.

3) The planned number of trips on the route X_{21} is taken equal to X_{13} in calculations, i.e., it is assumed that all scheduled trips are being operated.

4) The number of trips during the period under study f_{study} (X_{15}):

$$f_{study} = \frac{T_{study} \times A \times 60}{T_{turn}} \qquad (4)$$

where T_{study} – the period under study, in calculations it is equal to 1 hour.

In [15, Table 9] between the idle time at one terminal point T_{term} and the regularity of movement R, the following relationship is given (see Table 1).

Since, as is known from [15], the regularity is equal to the number of trips performed with allowable deviations, f_{allow} divided by the planned number of trips f_{pl}, the value f_{allow} (X_{19}) in the calculations will be determined as follows:

$$f_{allow} = R \cdot f_{pl}, \qquad (5)$$

where R corresponds to the value T_{term} (X_4), divided by two, since the input factor T_{turn} (X_3) takes into account the average idle time at both terminal points. Based on [3], the relationship between regularity R and allowable deviation from the schedule Δ can be taken as follows:

$$R_2 = \Delta_2 \cdot 0{,}09 \qquad (6)$$

or

$$f_{allow} = f_{pl} \cdot 0{,}3\Delta. \qquad (7)$$

Thus, the value of the input factor f_{allow} is determined step by step. First, depending on the selected value X_4 (idle time at terminal points), then it is adjusted depending on the accepted allowable deviation from the schedule (in calculations $X_5 \leq 3$ min).

5) Time of work of drivers on the route per day T_{lin} (X_7):

$$T_{lin} = T_d + 0{,}3N_D, \qquad (8)$$

where N_D – the number of drivers working on the route per day;

0,3 – preparatory and final time for each driver.

Selection of Initial Information for Calculations

The calculation was carried out for LIAZ-5292.60 bus, in accordance with which the values of the maximum capacity M_{max} (X_{16}) (the number of seats M_s (X_{17}) and the free floor area in the bus cabin S_{free} (X_{18}) are set.

In accordance with the requirements of the theory of experiment planning, they take the maximum and minimum values. For all basic factors, upper, lower and main (zero) levels are set.

The numerical values of these levels for each factor were determined based on the analysis of the actual values of technical and operational indicators on 71 routes of Moscow region. Factor X_1 (number of buses) has an upper level, which corresponds to the maximum number of buses on the route from among the considered ones (suburban and urban), i.e., six, and the lower level corresponds to one. The upper and lower levels of X_3 factor (turnaround time) are determined for each specific value of X_2 factor (route length), taking into account the fulfilment of the condition: the operating speed on the route takes a maximum value of 25,7 km/h and a minimum value is of 12 km/h. As a result (see Table 2), the upper level $X_2 = 29$ corresponds to the upper level $X_3 = 290$ and to the lower level $X_3 = 135$, the lower level $X_2 = 2{,}4$ corresponds to the upper level $X_3 = 24$ and to the lower level $X_3 = 11{,}2$.

Next, the variation intervals are selected (its own for each basic factor), equal to the half-sum of

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[2] Since the turnaround time depends on the length of the route, the operating speed is initially substituted into the matrix, and then, based on its value, the turnaround time is calculated.

Table 2

Table of levels of basic factors [compiled by the authors]

Levels	Factors									
	X_1 (pcs.)	X_2 (km)	X_3 (min)	X_4 (min)	X_5 (min)	X_6 (hour)	X_8 (hour)	X_9 (hour)	X_{10} (hour)	X_{11} (km)
Basic	3,5	15,7	73,1 157	6	2	42	6	6	3,84	122,5
Variation interval	2,5	13,3	61,9 133	4	1	30	4	4	2,74	137,5
Upper level	6	29	135 290	10	3	72	10	10	6,58	330
Lower level	1	2,4	11,2 24,0	2	1	12	2	2	1,097	55

Table 3

Numerical values of derived input factors [compiled by the authors]

№	X_{12}	X_7	X_{14}	X_{13}	X_{15}	X_{19}
1	2	3	4	5	6	7
1	12,0	12,3	64,3	64,3	5,36	45,55
2	12,0	12,3	2,48	2,48	0,207	3,78
3	12,0	12,3	30	30	2,5	21,3
4	12,0	12,3	5,33	5,33	0,44	3,78
5	12,0	12,3	37,5	37,5	3,125	29,7
6	12,0	12,3	5,03	5,03	0,4196	1,33
7	12,0	12,3	22,5	22,5	1,87	5,94
8	12,0	12,3	5,03	5,03	0,4196	3,32
9	72,0	73,8	386	386	32,16	274,06
10	72,0	73,8	180	189	15	127,8
11	72,0	73,8	32	32	2,67	22,72
12	72,0	73,8	225	225	18,75	339,68
13	72,0	73,8	34,5	34,5	1,21	11,48
14	72,0	72,8	135	135	11,25	35,64
15	72,0	73,8	30,2	30,2	2,52	7,98
16	72,0	73,8	14,89	14,89	1,241	10,57

the upper and lower levels of the factor. These levels and intervals of variation are presented in Table 2.

Characteristics of the demand for transportation on the route remain constant, the characteristics for the «network» are equal to zero, and the remaining input factors are calculated in accordance with functional dependencies. The results of calculations of the values of dependent (derivative) input factors are given in Table 3.

A complete factorial experiment, as it is well known, is an experiment in which all possible combinations of factor levels are implemented. If the number of levels of each factor is equal to two, then we have a complete factorial experiment of type 2^k, where 2 is the number of levels, k is the number of factors (see Table 4).

The conditions of the experiment are presented in the form of a table (a planning matrix), where the rows correspond to different experiments, and the columns correspond to the values of the factors.

The coefficients calculated from the results of the experiment indicate the strength of the influence of the factor. The value of the coefficient corresponds to the contribution of this factor to the value of the optimisation parameter when the factor moves from the zero level to the upper or lower.

Research Results Based on the Experiment Planning Method

As a result of the research, it was found that five basic factors affect Y_T, Y_N, Y_C and ten basic factors affect Y_E. The specificity of the problem is that for all four optimisation parameters, one and the same matrix can be constructed. To conduct a full factorial experiment with varying ten factors at two levels, it is necessary to carry out $2^{10} = 1024$ calculation options. However, in accordance with [14, Table 7.2] in this case, we can restrict ourselves to using 1/64-replicas from 2^{10} and carry out only $2^{10-6} = 2^4 = 16$ calculation options, i.e., 64 times less. When constructing an experiment planning matrix, there is no need to evaluate the effects of the interaction of factors, since the values of the optimisation parameters Y_T, Y_N, Y_C, Y_E for each row of the matrix were determined by the dependencies between the factors and parameters. To carry out

Table 4

Experiment planning matrix 2³ [compiled by the authors]

Experiment number	x_1	x	y	Experiment number	x_1	x_1	y
1	-1	-1	y_1	3	-1	+1	y_3
2	+1	-1	y_2	4	+1	+1	y_4

Table 5

Experiment planning matrix [compiled by the authors]

№	X_1	X_2	X_3	X_4	X_5	X_6	X_8	X_9	X_{10}	X_{17}	Y_T	Y_N	Y_C	Y_E
1	–	–	–	–	+	+	+	+	+	–	23,26	0*	0,905	71,47
2	–	+	–	–	–	–	–	+	+	+	101,06	7,39	0,88	53,15
3	–	–	+	–	–	+	+	–	+	+	12,28	0	0,92	101,63
4	–	+	+	–	+	–	–	–	+	–	99,54	2,27	0,811	103,88
5	–	–	–	+	+	–	+	–	–	+	27,26	0	0,898	59,73
6	–	+	–	+	–	+	–	–	–	–	103,54	2,49	0,806	84,85
7	–	–	+	+	–	–	+	+	–	–	16,18	0	0,91	73,57
8	–	+	+	+	+	+	–	+	–	+	203,56	7,49	0,606	104,85
9	+	–	–	–	+	+	–	+	–	–	13,32	0	0,904	388,85
10	+	–	+	–	–	+	–	–	–	+	8,77	0	0,9	521,1
11	+	+	+	–	+	–	+	–	–	–	43,29	2,23	0,813	560,32
12	+	–	–	+	+	–	–	–	+	+	13,97	0	0,898	271,87
13	+	+	–	+	–	+	+	–	+	–	86,85	7,64	0,677	399,16
14	+	–	+	+	–	–	–	+	+	–	8,86	0	0,901	403,76
15	+	+	+	+	+	+	+	+	+	+	43,97	2,49	0,81	497,33
16	+	+	–	–	–	–	+	+	–	+	81,51	7,396	0,68	304,7

* Occupancy (YN) equal to 0 means that all passengers in the bus are seated and none is standing.

calculations in accordance with the established dependencies of indicators and factors, values were set for all factors related to the input. These values are taken as follows based on the considered statistical data: at X_8 = 2,4 km X_{20} = 1.8 km; at X_2 = 29 km X_{20} = 8,9 km; X_{17} = 25 seats; X_{21} = 22 people with X_1 = 1 bus; at X_1 = 6 bus X_{21} = 132 people; X_{16} = 110 seats; X_{22} = 0,1 km at X_2 = 2,4 km and X_{22} = 0,3875 km at X_2 = 29 km; T_o = 12 hours; N_D = 1 person in each bus. Table 5 shows the experiment planning matrix with the values of the optimisation parameters calculated from the established dependencies for each row of the matrix.

Based on the results of the calculations presented in the experiment planning matrix, the coefficients in the regression equations for each of the optimisation parameters from formula (2) can be determined. However, for this sequence, there is no need to build regression equations since here it is necessary to determine the degree of influence of each of the factors on the optimisation parameters.

As shown in [14, Chapter 10], the regression coefficients obtained by calculations using the experiment planning matrix are identical to those that could be obtained as a result of calculations using the least squares method. Based on this, it is possible to calculate all the statistical characteristics of the basic factors necessary to determine the closeness of the relationship between the factors and optimisation parameters and between the factors themselves. The calculation results are presented in Table 6.

CONCLUSION

The experiment planning method used in the study made it possible to identify the factors influencing each of the four optimisation parameters.

An analysis of the pair correlation coefficients shows that the factors X_2 and X_3, and, consequently, the functionally dependent factors X_{13} and X_{15}, have the most significant influence on Y_T, Y_N, Y_C. The influence of X_{15} factor on occupancy (Y_N) and completeness of revenue collection (Y_C) is considered separately, since these parameters, based on the fact that they are calculated for peak hours, are more significantly affected not by the total number of buses on the route during peak hours, but by the number of trips performed by them (X_{15}) during this period.

The factor X_1 also has a significant effect on Y_T, Y_N, Y_C, however, the pair correlation coefficient r_{xly} has a low value, since the optimisation parameter Y_T includes four components, and the factor X_1 affects only one of the components of passenger time spending (Y_T) – T_{wait} (waiting time). The optimisation parameter Y_3 is most significantly

Table 6

Results of calculations of statistical parameters [compiled by the authors]

Statistical characteristic	Optimisation parameters			
	Y_T	Y_N	Y_C	Y_E
$\overline{Y_i}$	55,45	2,15	0,832	250,01
$\overline{X_1}$	3,5	3,5	3,5	3,5
$\overline{X_2}$	15,7	15,7	15,7	15,7
$\overline{X_4}$	6	6	6	6
$\overline{X_3}$	109,36	109,36	109,36	109,36
$\overline{X_5}$	2	2	2	2
$\overline{X_6}$	21	21	21	21
$\overline{X_8}$	6	6	6	6
$\overline{X_9}$	6	6	6	6
$\overline{X_{10}}$	1.92	1,92	1,92	1,92
$\overline{X_{11}}$	96,25	96,25	96,25	36,25
σ_{x1}	2,5	2,5	2,5	2,5
σ_{x2}	13,3	13,3	13,3	13,3
σ_{x3}	4	4	4	4
σ_{x4}	102,36	102,36	102,36	102,36
σ_{x5}	1	1	1	1
σ_{x6}	29,85	29,85	29,85	29,85
σ_{x8}	4	4	4	4
σ_{x9}	4	4	4	4
σ_{x10}	2,73	2,73	2,73	2,73
σ_{x11}	136,81	136,81	136,81	136,81
σ_Y	51,72	52,72	0,0849	181,83
r_{x1y}	-0,346	-	-	0,926
r_{x2y}	0,773	0,776	-0,843	0,074
r_{x3y}	0,146	0,073	-0,082	-0,072
r_{x4y}	0,813	0,987	-0,993	-0,037
r_{x5y}	0,183	0,35	-0,28	0,029
r_{x6y}				0,58
r_{x8y}				0,046
r_{x9y}				0,084
r_{x10y}				0,38
r_{x15y}		-0,542	0,499	
r_{x11y}				0,534
R	0,812	0,636	0,579	0,989

Note: $\overline{X_i}$, $\overline{Y}$ – arithmetic mean;
σ_{xi}, σ_y – standard deviation;
r_{xiy} – pair correlation coefficient;
R – cumulative correlation coefficient.

influenced by the factors X_1 and X_{11}. Although the obtained results confirmed the well-known dependence of the optimisation parameters on the factor X_1 (number of buses), at the same time they allowed us to rank the factors according to the degree of their influence on the result. At the same time, the correspondence of the obtained results to real and obvious dependencies allows us to conclude that the chosen method and its implementation are correct.

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Article received 24.08.2022, approved 12.09.2022, accepted 14.09.2022.