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Assessment of the Influence of Internal Factors on the Indicators of Passenger Elevator Units Utilization Based on the Results of Regular Monitoring

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Abstract

Introduction. Ensuring high reliability and safety of operation of passenger elevator units is largely determined by the implemented maintenance conditions (MC). The frequency of performing preventive actions depends, first of all, on the level of elevator utilization. Time, power indicators and the degree of remaining life are used to evaluate it. Among the time indicators, the net machine time coefficient (NMT) and the turn-on frequency are accepted, which are random variables depending on a number of internal factors characterizing the operating conditions of the unit. The work objective is to establish the relationship between the average values of NMT, as one of the main indicators of the load of the elevator unit, and the main internal factors.

Materials and Methods. The research was carried out on the basis of processing and generalization of statistical materials of dispatching control of time indicators of a number of passenger elevator units. 11 elevators were randomly selected, differing in the number of floors, the specific number of residents using the elevator, and the speed of movement of the cab. Graphical-analytic methods were used to construct empirical dependences of NMT on the number of residents, the speed of the cab and the number of floors of the building. Along with the technical parameters of the elevator, random changes in the NMT indicators for individual periods of the day were taken into account.

Results. Empirical dependences of the NMT on the main internal factors — the density of occupation, the number of floors of the building and the speed of the cab movement were established. Mathematical models provided results adequate to experimental values. The error when comparing the calculated data with the actual data did not exceed 10 % in most cases.

Discussion and Conclusion. The value of the empirical dependencies obtained consists in the ability to assess the workload of units during the current period of operation without additional multi-day measurements. Empirical formulas can be used as basic relations in simulation modeling at any stage of the life cycle.

Keywords: passenger elevator, technical condition, workload indicators, maintenance interval, machine time coefficient

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Научная статья

Оценка влияния внутренних факторов на показатели загруженности пассажирских лифтовых установок на основе результатов регулярного мониторинга

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Аннотация
Введение. Обеспечение высокой надежности и безопасности эксплуатации пассажирских лифтовых установок во многом определяется реализуемым режимом их технического обслуживания (ТО). Частота выполнения профилактических воздействий зависит прежде всего от уровня загруженности лифта, для оценки которого используются временны́е, силовые показатели и степень отработки ресурса. В качестве временны́х показателей приняты коэффициент чистого машинного времени (КМВ) и частота включений, которые являются случайными величинами, зависящими от ряда внутренних факторов, характеризующих условия эксплуатации установки. Целью данной работы является установление взаимосвязи средних значений КМВ, как одного из главных показателей загруженности лифтовой установки, и основных внутренних факторов.
Материалы и методы. Исследования выполнены на основе обработки и обобщения статистических материалов диспетчерского контроля временны́х показателей ряда пассажирских лифтовых установок. Случайным образом отобраны 11 лифтов в домах, отличающихся этажностью, количеством жильцов, пользующихся лифтом, и скоростью движения кабины. Для построения эмпирических зависимостей КМВ от числа жильцов, скорости кабины и этажности дома использованы графоаналитические методы. Наряду с техническими параметрами лифта учитывались случайные изменения показателей КМВ по времени суток.
Результаты исследования. Установлены эмпирические зависимости КМВ от основных внутренних факторов — плотности заселения дома, этажности здания и скорости движения кабины. Математические модели обеспечивают получение результатов, адекватных экспериментальным значениям. Ошибка при сравнении расчетных данных с фактическими не превышала в большинстве случаев 10 %.
Обсуждение и заключение. Значения полученных эмпирических зависимостей дают возможность оценивать загруженность установок в текущий период эксплуатации без проведения дополнительных многодневных замеров. Эмпирические формулы можно использовать в качестве базовых соотношений при имитационном моделирования в произвольной стадии жизненного цикла.

Ключевые слова: лифт пассажирский, техническое состояние, показатели загруженности, периодичность технического обслуживания, коэффициент машинного времени

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Для цитирования. Хазанович Г.Ш., Апрышкин Д.С. Оценка влияния внутренних факторов на показатели загруженности пассажирских лифтовых установок на основе результатов регулярного мониторинга. *Безопасность техногенных и природных систем*. 2023;7(3):34–43. https://doi.org/10.23947/2541-9129-2023-7-3-34-43

Introduction. Elevator unit utilization during operation depends on a number of internal factors, which include the number of floors of the building, occupation density of the building, the characteristics of the elevator unit, etc. The level of elevator utilization has a direct impact on the technical condition of its components throughout the entire life of the unit. One of the methods of ensuring the necessary technical condition of the elevator is its timely maintenance. A number of researchers have attempted to determine the optimal frequency of maintenance of elevators, taking into account the actual load of the system. In the work "On the control of the technical condition of elevator ropes based on artificial intelligence and computer vision technologies" AV Panfilov, AR Yusupov, AA Korotkiy, BF Ivanov considered the use of artificial intelligence and computer vision technology to control the technical condition of elevator ropes [1]. Researchers from China and the Netherlands analyzed a scientifically based choice of strategy and frequency of maintenance [2–6]. They came to the conclusion that the universal target function should be economic indicators. To justify such a decision, the statement is given that "maintenance and emergency failures are closely related to the reliability of elevator equipment, but differ in the nature of this relationship and economic consequences. The increase in maintenance costs leads to a reduction in emergency failures and to a reduction in costs associated with liquidation and losses due to downtime." Thus, on the one hand, the costs of maintenance are increasing; on the other hand, the costs of ensuring reliability are decreasing. Therefore, some universal ratio is taken as the objective function, for example, the so-called reduced costs, which takes into account the main economic components.

Modern dispatching control systems allow for constant monitoring of the elevator condition, as well as to obtain temporary indicators of the operation of its main components: the net duration of operation and the turn-on frequency of the main drive of the elevator[1,2]. On the basis of the listed time indicators, a methodology for determining the frequency of maintenance is built. Time indicators can also be attributed to operational data, on the basis of which the authors of the article previously conducted a study of cases of failures in the operation of passenger elevators [7, 8].

Materials and Methods. To assess the influence of internal factors on indicators of passenger elevator units utilization, the results of dispatcher records of temporary data on the operation of passenger elevator units in Rostov-on-Don were used, as well as the hypothesis about the relative duration of the machine cycle, indicating that the coefficient of the machine time of the elevator unit depends on the following main factors: the number of floors of the building— N, the number of tenants in the entrance — Z, the number of tenants using the elevator — Z_0, the average speed of the cabin — v_{cp}, m/s, load capacity — R, people, the number of apartments in the entrance — $M_{к}$, the number of apartments in the entrance, the residents of which do not use the elevator — $M_{к1}$ [9].

As shown in paper[3], the average machine trip time (excluding stops for passengers entering and exiting) is proportional to the number of floors of the building. This dependence is cited by DS Apryshkin in his dissertation "Assessment of the technical condition of machines with cable traction based on simulation modeling"[3].

For the purpose of the study, the authors selected 11 elevator units in residential buildings in Rostov-on-Don (Table 1). A preliminary analysis of the results of computer records of dispatching control showed that the values of NMT differ significantly during the day and at night [9].

Table 1

Initial data of the results of computer NMT control

Elevator no.	Address of the building and type of elevator / number of entrances	N/R	$M_к$/ $M_{1к}$, app.	Z, people	$v_{расч}$, m/s	Average NMT			Average turn-on frequency in min., NMT		
						day	night	general	day	night	general
1	Orbital'naya, 68/1	9/5	171/19	303	0.63	0.252	0.065	0.197	2.61	2.606	2.609
	Belyaeva, 22/2	9	212/20								
2	Passenger	9/5	106/10	144	0.63	0.119	0.036	0.095	2.361	2.380	2.366
3	Passenger	9/5	106/10	240	0.63	0.2	0.046	0.155	2.054	2.103	2.068
	Kapustina, 14/3	9	144/12								
4	Passenger	9/5	36/4	72	0.67	0.077	0.017	0.060	3.807	4.282	3.945
5	Passenger	9/5	36/4	99	0.67	0.085	0.02	0.066	3.067	3.360	3.152
6	Passenger	9/5	36/4	111	0.67	0.055	0.015	0.043	3.162	4.320	3.500
	Kosmonavtov, 37/2	18	140/2								
7	Passenger	18/5	35/2	65	0.91	0.167	0.031	0.127	2.004	2.367	2.110
8	Service	18/8	35/2	43	0.91	0.105	0.048	0.088	2.213	2.445	2.281
	Panovoi, 30/1	24									
9	Passenger	24/5	108/0	310	1.35	0.234	0.038	0.177	2.265	2.164	2.236
10	Passenger	24/5	108/0	347	1.35	0.276	0.05	0.210	2.219	2.433	2.281
11	Service	24/13	106/0	165	1.35	0.137	0.021	0.103	2.083	1.886	2.025

[1]*Dispetcherskii kompleks «OB»*. User's Manual. RE 3434-001-49739805-07. URL: https://lkds.ru/upload/docs/pdf/general/RE_3434-001-49739805-07_5.pdf (accessed: 11.04.2023).

[2]*Sistema liftovogo dispetcherskogo kontrolya i svyazi SLDKS-1*. User's Manual. P. 1. Product specification ESAN.484457.001RE. URL: http://www.mnppsaturn.ru/ftp/public/doc/sldks/re%20sldks-1m%201.pdf (accessed: 11.04.2023).

[3]Apryshkin DS. *Otsenka tekhnicheskogo sostoyaniya mashin s kanatnoi tyagoi na osnove imitatsionnogo modelirovaniya.* Author's abstract. Rostov-on-Don, 2023. 21 p. URL: https://www.dissercat.com/content/otsenka-tekhnicheskogo-sostoyaniya-mashin-s-kanatnoi-tyagoi-na-osnove-imitatsionnogo-modelir/read

Constant values of factors: h=3 m — interstorey distance; $N_н$=1 — the number of floors the residents of which do not use the elevator.

On the basis of the data presented, the dependencies of the machine time coefficient K_m on the number of passengers using the elevator, Z_0 are constructed (Fig. 1).

For elevators in buildings with 9 and 24 floors, NMT is statistically directly proportional to the value Z_0. The numbers of points on the graphs correspond to the data in Table 1.

The exceptions are the positions of points 4 and 6. These deviations in experimental dependencies are quite acceptable, taking into account the formation of pure machine operating time of the elevator as a stochastic process under the influence of many random factors. The graphs in Fig. 1 reflect the approximate position of the straight lines $K_{mэ}=f(Z_0)$, the exact position of the lines is obtained by the least squares method [10].

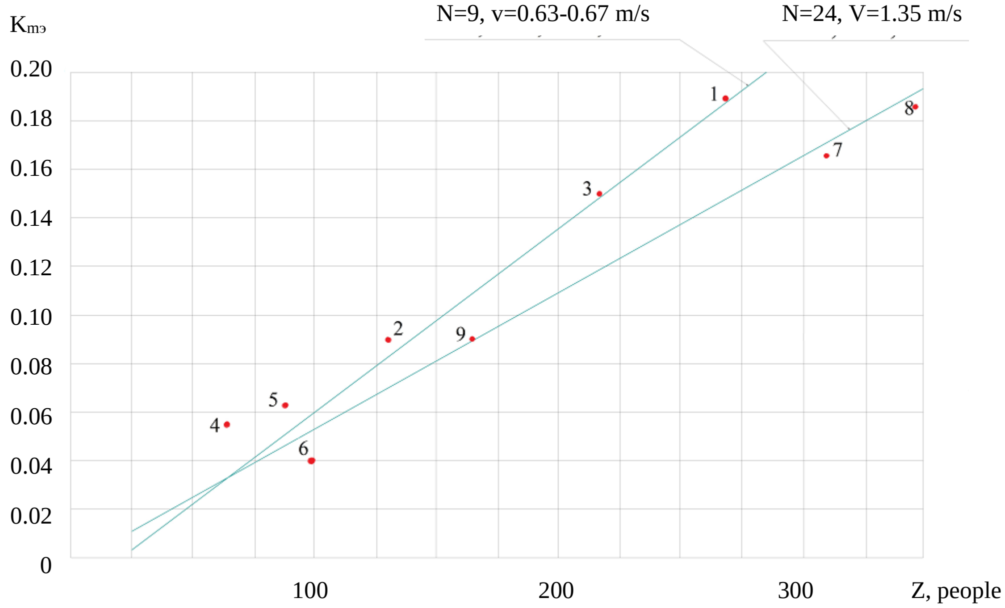

Fig. 1. Dependences of $K_{mэ}$ machine time coefficient on the number of residents using the elevator for average daily data processing

The graphs in Fig. 1 clearly show that NMT-$K_{mэ}$ linearly depends on the number of passengers using the elevator, Z_0, and with an increase in the speed of the cabin, *v*, NMT decreases.

When constructing mathematical model (1) of the average NMT value, a structure consisting of three factors was adopted: $\frac{\alpha_{m1}}{\lambda_н}$ — takes into account the angle of inclination of the straight line depending on the time period of the day; $Z_i(1-\frac{M_{k1i}}{M_{ki}})$ — the number of tenants using the elevator; $\Phi(\frac{v_{calc.i}}{v_{base}})$ — the function of NMT change from the ratio of the elevator speeds taken as the base, v_{base}, and the elevator with a specific speed, $v_{calc.i}$. Elevator N=9 with an average speed, v_{base}=0.65 m/s is taken as the base. In this case, the lines $K_{mi}=f(Z_i)$ pass through the origin:

$$K_{mi} = \frac{\alpha_{m1}}{\lambda_н} \cdot Z_i(1-\frac{M_{k1i}}{M_{ki}}) \cdot \Phi(\frac{v_{расч.i}}{v_{баз}}), \qquad (1)$$

where i=1, 2, 3 etc. determines the number of a straight line with a fixed value of the average speed of the cab, $v_{calc.i}$, along which the K_{mi} values are concentrated depending on the number of residents of the house (entrance) using the elevator:

i=1 — elevators with an average speed $v_{calc.1}$=0.63–0,65 m/s;

i=2 — elevators with an average speed $v_{calc.2}$=0.91 m/s;

i=3 — elevators with an average speed $v_{calc.3}$=1.35 m/s;

$\lambda_н$ — coefficients of NMT reduction in the night period, determined based on the processing of monitoring results (Table 1): for N=9 and v_1=0.63…0.67 m/s — $\lambda_{н1}$=3.0; for N=18 and v_2=0.91 m/s — $\lambda_{н2}$=3.5; for N=24 and v_3=1.35 m/s — $\lambda_{н3}$=4.0; for day mode: N=9, v_1=0.63 and 0.67 m/s — $\lambda_{н1}$= 0.773; N=18, v_2=0.91 m/s — $\lambda_{н2}$=0.721; N=24, v_3=1.35 m/s — $\lambda_{н3}$=0.669.

α_{m1} — angular coefficient of the basic dependence $K_{m1}=\alpha_{m1}\cdot Z_0$; for the rightmost point of the basic linear dependence at Z=303 people, Z_0=269 people, K_{m1}=0.197 we get (see the first line of Table 1):

$$\alpha_{m1} = \frac{0.197}{269} = 0.00073\ (\frac{ea.NMT}{people}).$$

$\Phi(\frac{v_{calc.i}}{v_{base}})$ — linear function that takes into account the influence of the ratio of the lowest speed, v_1=v_{base}=0.65 m/s, to the actual speed of the elevator, $v_{calc.2}$=0.91, $v_{calc.3}$=1.35 et al.

Let us set the form of the function $\Phi(\frac{v_{calc.i}}{v_{base}})$, using the data in Table 2. The function must pass through points α_{m1}, α_{m2} *and* α_{m3}. Table 2 provides numerical characteristics for these points.

Table 2

Numerical characteristics of points α_{m1}, α_{m2} *and* α_{m3}

Points	1	2	3
v, m/s	0.65	0.91	1.35
$K_{m.max}$	0.197	0.192	0.186
$Z_{0.max}$	269	300	347
α_{mi}	0.00073	0.00064	0.00054

The equation of a straight line passing through two points, 1 and 3

Let us denote $\alpha_{mi} = y$; $\frac{v_i}{v} = x$. Coordinates of points 1–x_1=1; y_1=1;
3–x_3=1.35/0.65=2.08; y_3=0.00054/0.00073=0.762. Equation of a straight line:

$$\frac{x-1}{2.08-1} = \frac{y-1}{0.762-1};$$

after simple transformations, we get y=1.22–0.22x.

Then $\Phi\left(\frac{v_{calc.i}}{v_{base}}\right) = 1.22 - 0.22\,\frac{v_{calc.i}}{v_{base}}$. Equation (1) takes the form

$$K_{mi} = \frac{\alpha_{m1}}{\lambda_{н}} \cdot Z_i \left(1 - \frac{M_{k1i}}{M_k}\right) \cdot \left(1{,}22 - 0{,}22\,\frac{v_{расч.i}}{v_{баз}}\right). \quad (2)$$

Results. Assessment of the calculation results reliability according to formula (2), $K_{mcalc.}$, in comparison with the data of dispatcher records, $K_{m.э.}$, is given in Table 3.

Table 3

Comparison of calculation results and dispatcher records data

No.	i	$V_{расч.i}$, m/s	Z_i, people	M_{k1i}, people.	M_{ki}, people.	$K_{m.расч.}$	$K_{m.э.}$
1	1	0.65	240	106	10	0.152	0.150
3	1	0.65	99	36	4	0.062	0.063
4	2	0.91	130	35	4	0.094	0.120
5	2	0.91	143	35	4	0.081	0.080
6	3	1.35	310	108	0	0.166	0.166
7	3	1.35	165	108	0	0.089	0.090

As can be seen from expression (2), the number of floors of building N is not explicitly included in the formula. Indirectly, the influence of N is manifested through Z_0. The influence of Z_0 (50...300 people) and $v_{calc.}$ (0.6…2.0 m/s) is shown in Fig. 2. As follows from these dependencies, with an increase in the average speed of the elevator, $v_{calc.i,}$ the NMT decreases almost proportionally. With an increase in the occupancy of the house, the NMT increases proportionally.

Thus, in a wide range of influencing factors, mathematical model (2) provides results adequate to experimental values (the deviation of experimental data in comparison with the calculated ones does not exceed 10 % in most cases) and allows predicting the value of NMT when the most important factors change — the density of occupancy of a building or entrance and the speed of movement of the cabin, on which the elevator equipment utilization largely depends.

At the same time, ratio (2) takes into account the influence of only two factors on the NMT: Z_0, and v_{cp}. The value of N is not directly included in the formula, which limits its application and reduces visibility in practical use. This formula generalizes only the set of data from regular observations limited by Table 1.

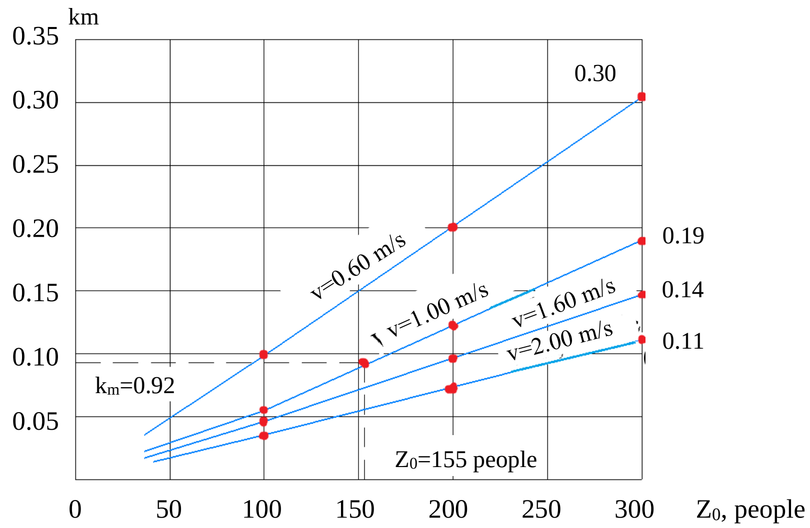

Fig. 2. Calculated dependences of NMT on the number of residents of the building (entrance), Z_0, using the elevator, and the average speed of the cab

Let us use another approach to derive the general ratio K_m=f(N, v_{cp}, Z_0). Previously conducted researches[3] proved that the average value of NMT is proportional to Z_0, and the proportionality coefficients for buildings of different floors differ significantly. So, for elevators N=9 and v_{cp}=0.63 m/s the coefficient characterizing the ratio of the increment of NMT Δ_{Km} to the increment of the number of residents using the elevator Δ_{Z0}, is $\frac{\Delta_{Km}}{\Delta_{Z0}} = 0.075\ \frac{ea.K_m}{100\ people}$, for elevators N=24 and v_{cp}=1.35 m/s — $\frac{\Delta_{Km}}{\Delta_{Z0}} = 0.055\ \frac{ea.K_m}{100\ people}$.

These data indicate the dependence of the specific NMT $\frac{\Delta_{Km}}{\Delta_{Z0}}$ (i.e., per registered tenant using the elevator) on two main factors — the number of floors of the building N and the average speed of the cabin v_{cp}.

With an increase in the number of floors, the average number of flights passed by an elevator in one cycle increases in direct proportion to the number of floors. With a constant number of cycles per unit of time to ensure the necessary capacity of the elevator, the machine cycle time will increase proportionally with the increase in the number of floors. With an increase in the average speed, the duration of the trip and the machine time are proportionally reduced.

If we denote the coefficient of influence of the listed factors N and v_{cp} on the specific NMT α_{Km}, then in the first approximation the dependence α_{Km}=f(N,v_{cp}) has the form:

$$\alpha_{Km}=\alpha_{Km0}+\frac{K_1 \cdot N}{K_2+v}, \tag{3}$$

where $\alpha_{Km0}=0.0004\ \frac{ea.K_m}{100 people}$ — the minimum value of the specific NMT recorded as a result of processing dispatcher surveillance data.

Using experimental data and the given logical reasoning, we obtain a generalized dependence of the specific NMT on N and v_{cp}:

$$\alpha_{Km}=0{,}0004+\frac{0{,}00228N}{v_{cp}-0{,}358}. \tag{4}$$

The dimension of quantity $[\alpha_{Km}]=\frac{ea.K_m}{100\ people}$. In expression (4), the specific NMT is proportional to the number of floors of the building and inversely proportional to the average speed of the cabin. The substantiation of the structure of formula (4) was made according to recommendations [10, 11], the selection of constants K_1 and K_2 was carried out according to the methodology [12, 13].

Dependences α_{Km}=f(N, v_{cp}) in graphical form in the ranges of variables N=(9…24), v=(0.6…2.0 m/s) are shown in Fig. 3.

Using an example for an elevator that is not included in the number of objects of regular observations, we will show the calculation of NMT using expression (4). Initial data: N=16; v_{cp}=1 m/s; Z_0=250 (2.5x100) people.

Calculation results:

$$\alpha_{Km}=0.0004+\frac{0.0228N}{v_{cp}-0.358}=0.0004+\frac{0.00228\cdot 16}{1-0.358}=0.0569\ \frac{ea.K_m}{100\ people}.$$

Estimated NMT of the elevator unit:

$$K_m=0.0569\cdot 2.5=0.142.$$

Formula (4) is valid for N=9…24, v_{cp}=0.6…2.0 m/s, with an arbitrary number of residents Z_0 and allows you to determine the preliminary value of the NMT when assessing the elevator mode of operation utilization.

It should be noted that strict regularities for another important indicator (the specific number of turns-on per unit of net machine time, n_{cp}) could not be established. Let us note that the relationship between K_m and n is not traced (Table 4 and Fig. 4).

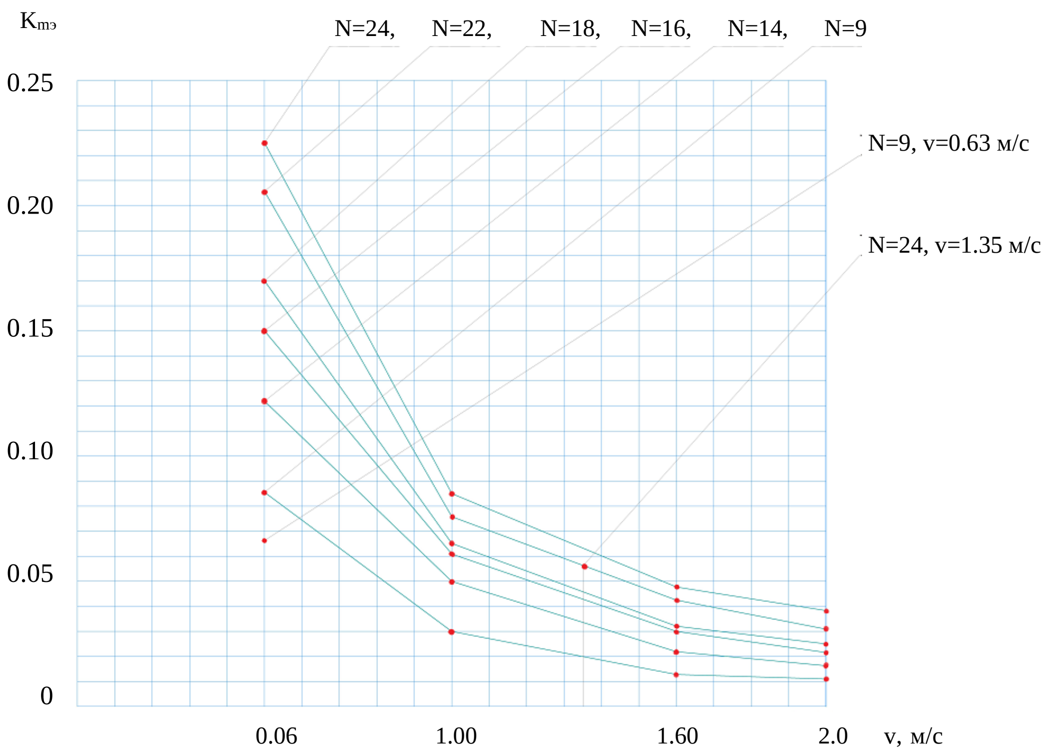

Fig. 3. Dependence of the specific NMT on the number of floors of the building and the speed of the elevator

Table 4

Average values of elevator operating modes

Elevator no.	1	2	3	4	5	6	7	8	9	10	11
NMT Coefficient	0.190	0.089	0.149	0.056	0.063	0.040	0.145	0.065	0.088	0.107	0.080
n, 1/min. NMT	2.45	2.13	1.90	3.43	2.75	2.86	1.95	1.83	3.08	2.25	1.89

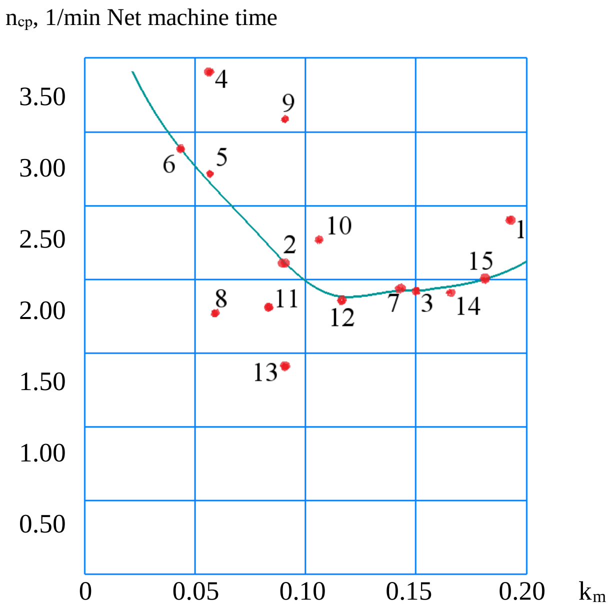

Fig. 4. Relationship of random values of $n_{cp.}$ and $K_{mcp.}$

The results of data processing of daily monitoring of the operation of elevator units with different characteristics in different types of residential multi-storey buildings, as well as of the same type or identical elevator units in one multi-entrance structure are presented in Table 4. The main indicators of the operation mode of the main drive of the elevator vary widely: NMT — five times, from 0.04 to 0.19, the number of turns-on per minute of net machine time — 1.87 times, from 1.83 to 3.43. NMT objectively characterizes the net time spent by all elements of the elevator in working condition, the values of this coefficient for most units are at a low level (0.05 ...0.2). This indicates a significant underloading of the main drive and other components. The specific number of turns-on determines the frequency of application of dynamic loads on the drive, ropes, cabin structure and other components. The characteristic value of the number of turns-on is from two to three per minute of net machine time, in terms of the hourly frequency of turns-on, this will be 120 ... 180 turns-on, which is quite acceptable for the engine, gearboxes and braking devices used.

Discussion and Conclusion. When designing and implementing maintenance systems for passenger elevator units, it is necessary first of all to determine the level of loading of their main power elements — the engine, gearbox, rope pulley, ropes, etc. [14]. Among the most important indicators of the degree of loading of the system, the NMT and the frequency of turns-on should be taken into account. The most reliable way to predict these indicators is statistical processing of dispatcher control data for the operation of elevators. The presented empirical dependences of the machine time coefficient on the number of floors of buildings, the number of residents using the elevator, and the speed of the cabin are also basic for the simulation of the time indicators of the operation of elevator units being put into operation, as well as elevators that are not equipped with a dispatch control system.

References

1. Panfilov AV, Yusupov AR, Korotkiy AA, Ivanov BF. On the Control of the Technical Condition of Elevator Ropes Based on Artificial Intelligence and Computer Vision Technology. *Advanced Engineering Research (Rostov-on-Don).* 2022;22(4):323–330. https://doi.org/10.23947/2687-1653-2022-22-4-323-330

2. Jae-Hak Lim, Dong Ho Park. Optimal Periodic Preventive Maintenance Schedules with Improvement Factors Depending on Number of Preventive Maintenances. *Asia-Pacific Journal of Operational Research.* 2007;24(1):111–124. https://doi.org/10.1142/S0217595907001139

3. Hongjiu Liu, Jiaxuan Wu. Research on Preventive Maintenance Strategy of Elevator Equipment. *Open Journal of Social Sciences.* 2018;06(01):165–174. https://doi.org/10.4236/jss.2018.61012

4. Li YH, Liu Z. Maintenance Interval Optimization Method Based on Improvement Factor for System Components. *Mechanical Engineering & Automation.* 2016;4:6–8.

5. Gia-Shie Liu. Three M-Failure Group Maintenance Models for M/M/N Unreliable Queuing Service Systems. *Computers & Industrial Engineering*. 2012;62(4):1011–1024. https://doi.org/10.1016/j.cie.2011.12.028

6. Almgren T, Patriksson M, Wojciechowsri A. Optimization Models for Improving Periodic Maintenance Schedules by Utilizing Opportunities. In: *Proceedings of the 4th Production and Operations Management World Conference.* The Netherlands, Amsterdam; 2012.

7. Khazanovich GS, Apryshkin DS. Modern condition monitoring systems of elevator units. Safety of Technogenic and Natural Systems. 2019;(2):37–40. https://doi.org/10.23947/2541-9129-2019-2-37-40

8. Shpet NA, Muravlev OP. Investigation of passenger lift failure by the operation data. *Bulletin of the Tomsk Polytechnic University*. 2013;323(4):123–126. http://earchive.tpu.ru/handle/11683/5035 (accessed: 12.06.2023).

9. Khazanovich GS, Apryshkin DS. Assessment of load of load-bearing elements of the passenger elevator based on regular monitoring results. *Safety of Technogenic and Natural Systems*. 2020;(1):32–42. https://doi.org/10.23947/2541-9129-2020-1-32-42

10. Gubanov VS. *Obobshchennyi metod naimen'shikh kvadratov*. Monograph. Saint-Petersburg: Nauka; 1997. 318 p. URL: http://pzs.dstu.dp.ua/DataMining/mls/bibl/gubanov.pdf (accessed: 12.06.2023)

11. Venttsel ES. *Teoriya veroyatnostei*. Textbook for universities. Moscow: Vysshaya shkola; 1999. 576 p.

12. Gnedenko BV. *Kurs teorii veroyatnostei*. Textbook. Moscow: Librokom; 2011. 448 p.

13. Gmurman VE. *Teoriya veroyatnostei i matematicheskaya statistika.* Textbook for universities. Moscow: Vysshaya shkola; 2003. 479 p.

14. Podberezina SG. Liftovoe khozyaistvo: organizuem sistemu planovo-predupreditel'nogo remonta. *Promyshlennaya bezopasnost'*. 2020;3:73–84. https://www.profiz.ru/pb/3_2020/lift_remont/ (accessed: 12.06.2023).

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