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Vertical transport: resource by the criterion of safety

Вертикальный транспорт: корректировка ресурса по критерию безопасности

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Abstract. The issue of engineering systems safety in particular of vertical transportation is revealed. Inconsistency in the implementation of theoretical developments in practice is defined because of the probabilistic calculation of the parameters modeled by monotone-logical functions, when real systems are non-monotone functions. The duality of the results of the processes theoretical description is revealed. A typical algorithm of safety analysis is based on the deductive abilities of a researcher when drawing up a scenario of possible hazardous situations, their development and possible consequences. Critical analysis of the regulated risk assessment procedures FMEA / FMECA was carried out when compiling the criticality level matrix of the event or process. Conceptually, the risk analysis is represented by a sequence of logical steps that provide a systematic approach to the identification of hazards associated with the operation of vertical transportation. It is suggested to supplement the methodology for data records of the loss time during the nonproduction downtime with the safety parameter assessment. The condition of the vertical transportation systems and the parameter deviation vector in the dual risk-safety system are established by introducing a variable value of the parameter in the probabilistic polynomial of the simulation event model. The obtained result is universally applicable, which allows us to approach to the value of the simulated criticality of the parameter through the variability of the calculations. The developed method imposes constrains on the compilation of a logical chain of assumptions in the program of the experimental research. It also allows creating adequate conditions for the operating of the physical model of the system. The modified methodology suggests table compiling of the parameter variation limits ranging the hazard rate and calculating the corresponding values of hazard factors. It is suggested to apply the developed methodology as the supplement to the existing general methodology for risk assessment at all stages of the service time of vertical transportation. The example of the implementation of the modified procedure. The developed service life parameter adjusting method reduces operation costs, ensures safety and stability of the public mobile movement abilities when using vertical transportation.

Аннотация. Раскрыта проблема решения задач обеспечения безопасности технических систем, в частности вертикального транспорта. Установлена несогласованность реализации теоретических разработок в практике из-за вероятностного исчисления параметров, моделируемых монотонно-логическими функциями, когда реальные системы представляют собой немонотонные функции. Выявлена дуальность результатов теоретического описания процессов. Типовой алгоритм анализа безопасности, базируется на дедуктивных способностях исследователя при составлении сценария возможных аварийных ситуаций, их развития и возможных последствий. Выполнен критический анализ регламентированных методик оценки риска FMEA / FMECA при составлении матрицы критичности события или процесса. Концептуально анализ риска представлен последовательностью логических шагов, обеспечивающих системный подход к установлению опасностей, связанных с эксплуатацией вертикального транспорта. Предлагается дополнить методику учета потерь времени при непроизводственных простоях, оценкой показателя безопасности. Состояние систем вертикального транспорта и вектор отклонения показателя в дуальной системе риск-безопасности устанавливается путем введения вариативного значения параметра в вероятностный полином на имитационной модели события. Получаемый результат универсален. позволяет приблизиться к

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значению условной критичности показателя через вариативность исчисления. Разработанный метод накладывает ограничения при составлении логической цепочки допущений в программе экспериментальных исследований, позволяет создать адекватные условия функционирования физической модели системы. Модифицированная методика предполагает построение таблиц пределов изменения параметров с установлением тяжести проявления опасности и вычислением значений соответствующих им величин поражающих факторов. Предлагается применить разработанную методику как дополнение к уже имеющейся общей методологии при оценке риска на всех стадиях жизни вертикального транспорта. Составлен типовой алгоритм обеспечения безопасности компонентов с сопоставлением срока службы элементов лифта. Дан пример реализации модифицированной методики при установлении остаточного ресурса элементной базы лифта. Разработанный метод корректировки ресурсного показателя снизит затраты на эксплуатацию обеспечит безопасность и стабильность мобильного перемещения граждан при использовании вертикального транспорта.

Introduction

The technical regulations of the Customs Union state the service life of the various technical systems life cycle as an important factor in determining the probability of the hazardous event under analysis (Federal Law No. 184-FL of 27.12.2002 "On Technical Regulation"; Technical Regulation of Customs Union (TR CU) 011/2011 Safety of Elevators). Statutory regulation meets the requirements of the following documents: Russian State Standard GOST R 53387-2009 (ISO / CU 14798: 2006) Elevators, escalators and passenger conveyors. Methodology for analysis and risk reduction; Russian State Standard GOST R 54999-2012 (EN 13015: 2001) Elevators. General requirements for the instructions for technical maintenance of elevators; Russian State Standard GOST R 55964-2014 Elevators. General safety requirements for operational service.

TR CU 011/2011 "Safety of elevators" provide for the formulation of the scenario, including hazards, hazardous situation and the causes, as well as possible consequences, i.e. the identification of damage probability. In many cases risk characteristics cannot be precisely defined, only their level can be determined. That primarily applies to determining the probability of possible damage. TR CU 011/2011 "Safety of elevators" state four (1-4) levels of severity of possible damage, whereas while performing the risk analysis six (A-F) levels of damage probability are determined.

The design and maintainability risk assessment of elevators allows us to evaluate the safety level of the equipment, its components and related control procedures. The regulations of ISO / CU 14798: 2006 state elevators, escalators and passenger conveyors risk analyses subject as the following: complete elevator, escalator, passenger conveyor; components or systems of equipment; people dealing with the equipment; processes associated with the equipment and its components [1, 2].

The regulation establishes the stages of both analysis and risk reduction procedure. One of the steps is determination of the risk analysis subject and analysis-related factors (TR CU 011/2011 Safety of elevators, Russian State Standard GOST R 53387-2009 (ISO / CU 14798: 2006) Elevators, escalators and passenger conveyors. The methodology for analysis and risk reduction, Russian State Standard GOST R 55964-2014 Elevators. General safety requirements for operational service).

The scientists studying this problem put the notion of "acceptable risk" to use as a compromise solution. The main part of the conclusions and recommended methodologies is based on the statistical data compilation, on the acceptance of a certain set of assumptions, on the apriority of the proposed scenarios for the situation development and on the relativity of the results. Additional research, refinement of the previously obtained results lead to inconsistency, i.e. the scientist makes assumptions based on the statistical data of the previous studies which already include certain percentage of assumptions. These result in paradox – that is, an attempt to clarify the result of the previous studies leads to an increase in the logic-probabilistic influence as well as to an increase in the subjectivity of the suggested logical function. The article [3] presents a methodology for quantifying the risk of failure of lifting equipment, based on logic and probabilistic risk analysis techniques and the method of expert estimates. The article [4] gives an account and analysis of the accuracy of assembly variations in the parameters of the stress-strain state – according to values of assembly (initial) efforts. The author suggests constructive solutions for joining rods and installation method for coatings, which are aimed at increasing their load-bearing capacity, longevity and assemblability. The article [5] defines the ways of lifting unbalanced loads. Discusses the equipment for lifting is not balanced cargo. The article [6] gives an overview and analysis of the models of the damage accumulation in monolithic materials when exposed to prolonged and repeatedly applied load. The application of the principle of equivalence stress in the continuous and damage body allowed introducing into the strength criterion of Pisarenko-Lebedev and the three-parameter plasticity condition of Coulomb-Mohr the measures of the theory to accumulate damage in capacity of which the damage of Y.N. Rabotnova and the continuity of L.M. Kachanov are used. It was found that when exposed to repeated load, the process of the reduction of the continuity and the increase in the damage is hereditary. Therefore, to predict changes in these measures under the action of cyclic loads the integral equations of the theory of heredity are applied. In [7, 8], synergetic principles and mathematical apparatus of catastrophe theory were used to model the processes of destruction of polymeric materials. In polymeric materials, the process of accumulation of damages at various scale levels is proposed to be taken into account through the synergetic effect, the calculation of which in this work was carried out using the mathematical apparatus of catastrophe theory. It was found that a structure of any constructional material as a mechanical system possessed spatial and time properties and to study them a transition from the material structure to the cybernetic one was done. A formation process description of a new structure of the cybernetic system was suggested to do, using the information theory instrument. The authors [9] present a research of the opportunity to construct a sustainability model of life support systems under different emergency situations in respect of modern current trends in the development of information-analytical systems and principles of systems engineering approach.

It should be noted that the calculation methods imply the logic-probabilistic calculation of parameters, where the function arguments are both dual and Boolean variables. Mathematical calculi simulate monotone logic functions, although in reality the systems are non-monotone functions.

The implementation of the concept of complete or "absolute" human safety in the production sphere is an insurmountable task due to a number of reasons:

– engineering tools for performing work processes are technologically imperfect;

– the research methods that do not exclude randomness of hazardous situations during the operation of technical equipment and machinery are theoretically probabilistic.

The purpose of the research is to ensure the stability of the public mobile movement abilities while using vertical transportation by adjusting service life parameter of the elevator elements in accordance with the criteria of failure risk and safety throughout the entire period of their operation.

Research problems:

1. To carry out assessment of efficiency of application of techniques of assessment of risk of FMEA/FMECA making matrixes of criticality of an event in case of the decision of tasks of safety of vertical transport.

2. To consider the object and parametric characteristic of elevators, escalators and passenger pipelines taking into account factors of influence on origin of risk of a failure.

3. To set a level of variability of a resource index of vertical transport by development of scenarios of possible alert conditions

4. To develop the modified technique of assessment of safety of the elevator allowing to adjust conditions of technical maintenance and the requirement to the load modes of an element basis.

5. To make a safety algorithm with comparison of service life of elements of the elevator.

6. To give a technique example of implementation in case of establishment of a residual resource of an element basis of the elevator and change of an index of probability risk failure.

Basic aspects of the logic of compiling the mathematical model of the non-monotone function in the engineering system safety assessment.

From the point of view of reliability and safety, the processes occurring in the engineering systems when operating machinery and equipment can definitely be classified as irreversible.

The scheme of service support offered by manufacturers is aimed at maintaining the normative level of operability throughout the service life period.

From the point of view of the process theoretical description, the function arguments of the system are dual Boolean variables, i.e. carrying out the research suggests obtaining double results.

For elevator equipment, which is a technically complex system, danger is manifested in the form of failure of various structural elements with different levels of influence on safety. From now forth, it is accepted to characterize the possibility of a dangerous situation as failure, and the research is aimed at the establishment of the criteria throughout the entire operation period of elevators.

During the machine or equipment operation a failure is probable (P), whereas the safety of the process is ensured by a normative safety level (E) for a single situation under the specific conditions of both external and internal environment factor influence typical only to the above single situation. ((E = 1- P) it is assumed to present these values ranging from 0 to 1). One of the boundary values has the form P (E = 1) represented by a probabilistic polynomial of n variables P (x_1), ... P (x_n) [2, 10, 11].

Relying on the logic of the speculations on duality, the domain of the system existence is in two boundary states:

– "zero probability of a failure" - "absolutely safe system", P = 0: 1 ↔ E = 1: 0, the Boolean algebra allows presenting it as a logical expression P ↑ ↓ E. This idealized state of the system cannot be implemented.

– the scheme "danger of the situation - complete lack of safety" refers to the category of hazardous situations.

In the given example the duality is also inherent to the criterion assessment of the risk of failure in the design of the elevator, its different elements.

The logic of reasoning implies the presence of intermediate parameters, which many calculation methodologies rely on.

The basic methodologies of reliability and risk theories allow us to use the computational method to perform tasks connected with risk, reliability and the systems safety assessment. The standard safety assessment algorithm is commonly known, it is based on the deductive abilities of the researcher while drawing up the scenario for possible hazardous situations, their development and possible consequences. Simulating the event on the computational model by introducing a variable value of the parameter into the probabilistic polynomial, the state of the system and the deviation vector of the parameter are established in the dual risk-safety system. It is assumed that both physical and simulation modeling has a certain spread of data due to misperception of the phenomena by the researcher.

Methods

Analysis of the main statements of the regulation

According to FMEA or FMECA methodologies, functional safety is assessed by the criticality rating of the event or processes. The criticality rating is established according to the matrix compiled for each case on the basis of expert analysis. It should be noted that assessing the total risk, FMECA suggests the ranking system of the event contribution with the description of the factor interaction focusing on the acceptability parameter. For the systems with high risk or high complexity of the design it is recommended to use probabilistic risk analysis [7, 11–13].

The classical models of the quantitative evaluation are based on the mathematical models of both cost calculations and identification of the nondimensional value of the composite parameters. In particular, the reliability composite parameters are identified as failure free performance, durability and maintainability quantitatively represented by generalized formulas including loss factor as an indicator of a separate property:

$$k_f = \frac{1}{\left(1 + \frac{t_{atf}}{t_{atbt}}\right)}, \tag{1}$$

where k_f – is the loss factor due to elimination of technical failures,

t_{atf} – is average time to eliminate one failure (design or production defect) during working hours, hour;

t_{atbf} – is average time between failures (design or production defect), hour.

The average time for elimination of one failure during working hours is directly dependent on the maintainability of the machine; organizational and production characteristics and the means of performing service works as well as indirect parameters of climatic conditions.

Technical failure due to the design or production defect depends primarily on the quality of the design and calculation works performed at the design stage and their implementation in production. It should be noted that a defect is inherently a failure having a random character and it is probabilistically difficult to define.

It is suggested to supplement the methodology for recording the time loss data during the non-productive downtime with the safety parameter record which is quantitatively expressed by the loss factor because of the elimination of the consequences of the hazardous situation:

$$k_f^{es} = \frac{1}{\left(1 + \frac{t_{atec}}{t_{adti}}\right)}, \tag{2}$$

where k_f^{es} is the loss factor due to elimination of the consequences of the abnormal or emergency situations

t_{atec} – is average time to eliminate the consequences of the hazardous situation, hour,

t_{adti} – is average duration of technical preventative measures taken against the hazardous situation for one technological machine, hour.

Further theoretical development is aimed at the refinement of the main aspects of the methodology for assessing the risks of elevators, escalators and passenger conveyors.

Conceptually, risk analysis is represented by a sequence of logical steps that ensure a systematic approach to the determination of hazards associated with the operation of vertical transportation.

This methodology regulates the events that can lead to damage of the different level, regulated in ISO / CU 14798: 2006.

The next requirement for the risk assessment is the effectiveness of all the available information records and the collection of data that allow qualitative hazard analysis, which is in good agreement with the previously suggested theoretical approaches to the influence factor consideration and the equipment element contribution to the overall safety concept of the operation facility.

Methods and Results

The development of the modified risk assessment methodology

The basic methodology for the reliability assessment of the machine / equipment determins the interrelationships of the probabilities of the operational state $P = P\left(T_{P\gamma}\right) = \frac{\gamma}{100}$ of its assembly units $P_{ij} = P\left(T_{\gamma ij}\right) = \frac{\gamma_{ij}}{100}$ within the operation period [1, 2].

As the limiting state of the engineering system is determined by the simultaneous limiting state of the assembly units of the system, the influence factor determined by the type of element connection becomes significant: successive connection ($P \le \prod_{i=1}^{J} P_i$); parallel connection ($P \le 1 - \prod_{j=1}^{k_i}\left(1 - P_{ij}\right)$).

Considering vertical transportation as a complex technically unsafe system with various factors of influence on risk-failure within the random operational period, the concept of "time lag" is introduced. This concept is mathematically described by Boolean algebra tools as a unit monotone function: $y_1^i\left(X_m\right) = y\left(x_1,\ldots,x_{i-1},1,x_{i+1},\ldots,x_m\right)$.

Inherent characteristic of the logical function is variability, the function arguments are Boolean variables (x_1).

The variability of the equipment elements state is represented by "zero", "physical" (real) and "unit" function having a general form $\left[y(X_m)\right]$. Mutual influence within a certain operational period is expressed by the equation: $\left\lfloor y_0^i(X_m)\right\rfloor \subseteq \left[y(X_m)\right] \subseteq \left\lfloor y_1^i(X_m)\right\rfloor$, in which the elevator is represented as a functional system consisting of m elements.

Using Boolean tools, we preset the safety parameter via the conjunction operator and the risk parameter via the disjunction operator. The inversion operator shows the compatibility of the hazard - safety levels: $E \leftrightarrow 1 \subseteq P \leftrightarrow 0$.

The obvious consequence of the above logical-mathematical steps is the function of the hazardous situation P_c probability during the operation of vertical transportation: $P_c = P\left(y\left(X_m\right) = 1\right)$.

Considering the factors of the influence on the hazardous situation, a conditional parameter characterizing "the event contribution" to safety is introduced:

$$B_i = P_i \xi_i \,, \tag{3}$$

where B_i is conditional indicator characterizing the "event contribution" to the element safety of the system;

$\xi_i = P\left(\Delta_x q\left(X_m\right)\right)$ is the partial derivative of the probability of the system dangerous operation.

$q_i = \sum_{i=1}^{k} 2^{-(r_i - 1)} - \sum_{j=1}^{e} 2^{-(r_i - 1)}$ is the level of the deviation vector of the "risk-safety" system probabilistic state for the elements of the complex engineering system, in our case, elevators, as the most mass representatives of the vertical transportation types;

e – is a number;

r_i – is a rank.

Taking into account the previous influence factors, the model for the elevator safety assessment within the actual operational period is presented by the following expression:

$$\xi_i = P_{C_1}^i - P_{C_0}^i \,, \tag{4}$$

where P_{C1i} is the probability of a dangerous situation throughout the operational period under observation, considering one of the failure criteria;

P_{C0i} is the probability of a dangerous situation in the initial operation phase considering one of the failure criteria.

– "contribution of the event":

$$B_i = P_C - P_{C_0}^i \,, \tag{5}$$

– relative contribution:

$$b_i = \frac{\xi_i P_i}{P_C} \,. \tag{6}$$

Using the given methodology, you can adjust the conditions of technical operation, the requirements for load modes which ensure safety without design modifications.

Furthermore, this methodology allows us to ensure the safety of the system through the main parameter of the components performance in the system such as a set of energy data

$$\overline{F_{эн}} = \frac{m'' - m_{Nom}}{r \cdot m''} \,. \tag{7}$$

where m '' – is the minimum severity of danger;

m_{Nom} is the nominal level of the danger severity.

Table 1. Danger severity aftereffects classification of failures and failure frequency (100 elevators) (in accordance with the analogue SAE J1739)

Danger severity aftereffects	failure criterion	Rank	Frequency of failure
Missing	No aftereffects	1	Up to 0.010
Very slight	Finish of the object does not meet the requirements (noise). The defect is noticed by picky users of the elevator (less than 25%)	2	0.1
Minor	Finish of the object does not meet the requirements (noise). The defect is noticed by 50% of users of the elevator.	3	0.5
Very low	Finish of the object does not meet the requirements (noise). The defect is noticed by most users (over 75%).	4	1
Low	The elevator is operative, but comfort/convenience system is poor and ineffective. Users of the elevator are quite unsatisfied.	5	2
Medium	Elevator is operative, but comfort/convenience system is inoperative. Users of the elevator feel uncomfortable (There is probability for people to get injured, that may pose harm of medium severity to human health).	6	5
High	Elevator is operative, but the efficiency is low. Elevator users are very dissatisfied (There is probability of serious injury to humans).	7	10
Very high	Elevator is inoperative (loss of primary function) (There is probability of either severe injury to humans or fatal outcome).	8	20
Dangerous with danger warning	There is a very high level of severity when a potential failure affects safe operation of the elevator and/or leads to the safety standards discrepancy warning of danger (There is risk of severe injury/fatal outcome)	9	50
Dangerous without danger warning	There is a very high level of danger severity when a potential failure affects safe operation of the elevator and/or leads to the safety standards discrepancy without warning of the danger (There is risk of severe injury/fatal outcome).	10	100

Characterizing the severity of danger, it is necessary to come from the qualitative characteristics to the quantitative analogue. We will assess the severity by the possible damage to the person. It is logical to classify a scenario as of high severity if it results in the person's social opportunity restriction in realizing his or her potential, i.e. infliction of health harm, which cannot be recuperated morally and / or physically.

The parameter of the empirical minimum value of danger severity is determined and the proportionality coefficient having the dimension of the damaging factor is justified.

It seems to be correct to come from categorizing the danger severity as "death" to such notion as "loss of social level” which means the person is alive, but with physical or moral limitations with discreteness of 1x1000:

1 is high = 0.5 * 10-3 (the person is alive, but is able to function 50%);

2 is average = 0.25 * 10^{-3} (reversible incapacitation requiring a certain period of rehabilitation);

3 is low = 0.15 * 10^{-3} (transfer of danger to a stressful situation, rapid recovery);

4 is negligible = 0.

The parameter is accepted on the basis of the concept of the dangerous situation criticality assessment considering human beings, according to the methods developed in the national standard of the Russian Federation "Risk Management. Analysis method of the types and failure aftereffects", which was introduced by Decree of the Federal Agency for technical regulation and metrology on December 27, 2007. article No. 572, which is modified in relation to the international standard IEC 60812:2006 “Analysis methods of system reliability. The analysis method of failure types and aftereffects (FMEA)".

The deviation of parameters from the standard ones, in terms of the danger severity and the risk of a mortal danger for humans is expressed respectively:

$$\Delta_m = \frac{m''_{av.calc}}{m''_{nom}} \qquad \Delta_p = \frac{P_{calc}}{P_{nom.}}. \tag{8}$$

where $m''_{av.calc}$ is the actual value of the danger severity of the lethality risk demonstration;

$P_{calc;\ nom}$ is the probability of the system failure situation with lethality risk, calculated and nominal respectively.

It should be noted that the shifting coefficient of the middle degree of the danger severity plays an important role

$$b = 1 - \eta \ln P, \tag{9}$$

where η – is the shifting coefficient.

P – is the probability of the system failure with the risk of fatal outcome.

By varying the severity limit value (upper - lower limits) we can determine the shifting coefficient, and by making the infogram, we can visually assess the consequences of lowering the limits, which in turn will allow determining the weight limits of the system taken as a whole.

Block diagram of the algorithm for ensuring the safety of components with comparison of the service life of the of the elevator elements is presented in Figure 1.

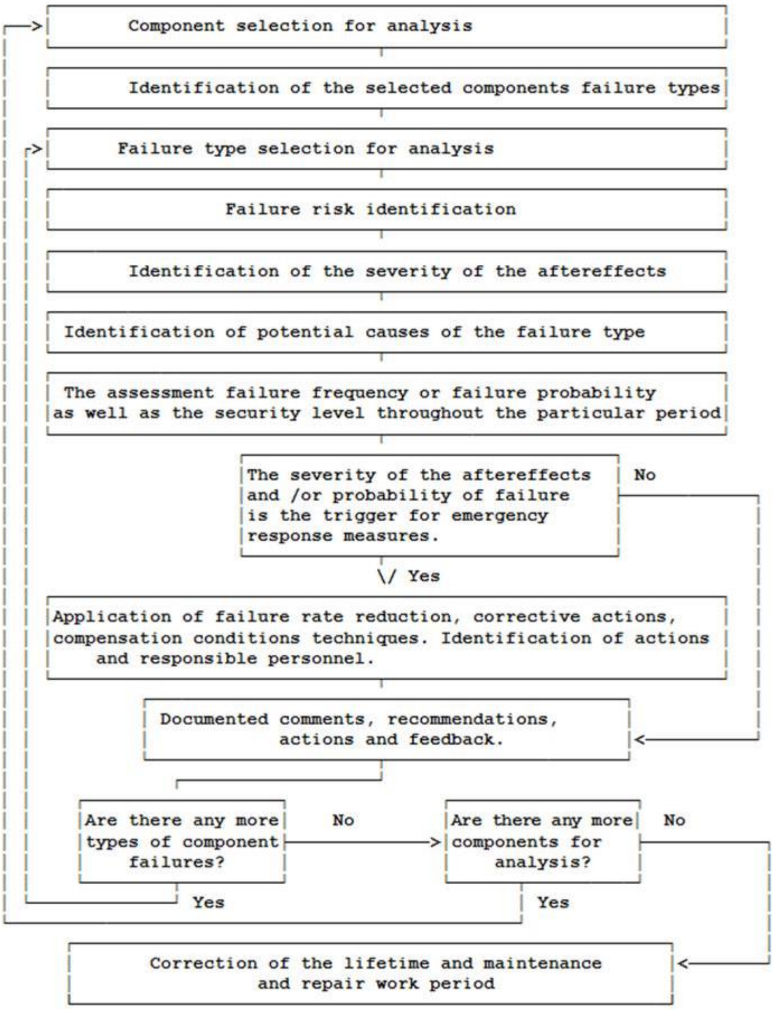

Figure 1. Block diagram of the algorithm for ensuring the safety of components with comparison of the service life of the of the elevator elements

As a result, it becomes possible to determine the safety conditions according to the various criteria.

The typical algorithm of components security with comparison of the service life of the components is made on the basis of the risk assessment scheme methods FMEA or FMECA. As a result, it becomes possible to determine the safety conditions according to the various criteria.

The modified methodology implies compiling the tables of limits of parameter range with determining danger severity as well as calculating the corresponding values of the damaging factors.

It is suggested to apply the developed methodology as the supplement to the existing general methodology for the risk assessment at all operation stages of elevators, escalators and passenger conveyors.

The example of the implementation of the modified methodology when determining the residual operation life of the elevator elements

The initial stage of the elevator safety assessment requires quantifying the gamma-percentile life value

$$T_{\gamma ij} = \frac{T_\gamma k_{ij}}{N_{ij}}, \tag{10}$$

where T_γ is gamma-percentile life of the equipment. It is taken according to the manufacturer's operational documentation;

k_{ij} is coefficient that allows for the use of assembly units / elements according to the time (0 < k_{ij} <1)/

This parameter for a specific component is determined on the basis of the technological cycle analysis of the equipment operation. So, for the engine, control elements and other assembly units of the elevator $k_i = 1$, we take $k_i = 0.75$ considering the time factor of usage, the intervals of the elements operation, and we take $k_i = 0.15$ allowing for the frequency of the backup system activation.

N_{ij} is the multiplicity of the replacement of the *i*-jth component before the operation period is finished, which corresponds to the limiting state of the equipment. The acceptance of any given value is based on the provision that the elevator components are operated until they reach the limiting state with repetitive replacement until the elevator reaches the limiting state and it is written off the inventory [8, 10–12, 14–16].

Using manufacturers data, the whole elevator design is assessed and the elevator elements are grouped according to the service life parameter : 7 objects – 25 years; 2 objects – 15 years; 16 objects – 12.5 years; 1 objects – 10 years; 6 objects – 5 years (fig.2, top-left box).

As statistical analysis shows, most times elevator structural elements fail in the mechanism, which plays a key role and is the most loaded, that is elevator drive, its elements have different service life parameters specified by the manufacturer, they are Electric engine – 15 years; Reducer, Braking device – 12.5 years; the outlet box – 10 years; Rope driving pulley – 5 years (fig.2, top-right box).

According to the manufacturer initial data, ensuring the components safety algorithm with the comparison of the elevator elements service time is carried out (Fig. 2).

The authors compiled statistics on the elevator failures in residence buildings with different operating periods in Moscow and Moscow region within the framework of expert evaluation of residual operation life. A fragment of the calculations is presented in table 2, where the sample elevator components making a significant contribution to predicting the risk of failure were chosen (the state of danger and guaranteed safety) [2, 11, 14].

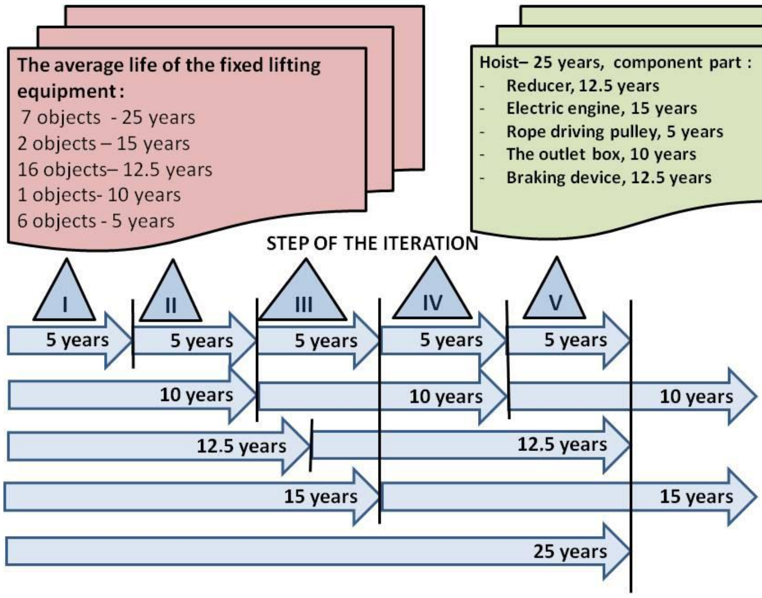

Figure 2 Algorithm for ensuring the safety of components with a comparison of the lifetime of the elements of the elevator

Table 2. A fragment of the calculations, where the sample elevator components making a significant contribution to predicting the risk of failure were chosen

Components of elevator equipment	Conditional indicator which characterizes "the contribution of events" to the security for the elevator element, Bi	Inversion operator (comparison of the levels of risk and safety)	
		$E \leftrightarrow 1$	$P \leftrightarrow 0$
Cabin and shaft doors	0.387	0.880	0.120
Lifting mechanism equipment	0.064	0.990	0.010
Shaft equipment	0.129	0.980	0.020
Drive system	0.096	0.996	0.004
Control system	0.291	0.900	0.100
Alarm unit	0.032	0.999	0.001

At the initial stage of implementation of the developed technique, elevator elements uniform wear is assumed, which is expressed in a 4 % decrease in efficiency per year of normal operation. It is calculated that if the maximum elevator service life is 25 years, in accordance with the manufacturer consideration, service life loss for a year will not exceed 4 %, on condition that the requirements of the qualitative normal operation are observed, repair and maintenance work is carried out with high standard of quality and on time. (The beginning of operation is 100 % – full service life, the end of operation is in 25 years, which is 0% of the service life, the calculations give the value of 100 %:25 years = 4 % for 1 year).

At the initial stage of the developed methodology implementation, it is assumed that the elevator equipment elements wear is the same; it is expressed by 4 % performance degradation per year of normal operation.

An additional requirement for safety is establishing the interdependence of the elements. This is justified by the fact that the elevator design allows for the stand-by system of the individual elements to reduce the risk of a hazardous situation. At the same time, when the backup system is activated, the elevator passes into the mode of abnormal operation conditions requiring the delivery of the passengers to the nearest floor and ensuring the possibility for their evacuation from the cabin. It is logical to conclude that this state is also included in the list of non-safe conditions [2, 3, 9, 14, 17–21].

During the entire service life, the residual operation life decreases taking into account the repetitive replacement of life expired elements, and so, the elevator safety level is calculated:

$$E = \sum_{i=1}^{n} (1 - q_i) \qquad (11)$$

where q – is the level of the deviation vector of the probabilistic state of the system "risk – safety" for the complex technical system elements, in the proposed design methodology it presents a reduction factor of the service life, defined as the ratio of the actual period of operation to the stated service life;

i – is the number of structural elements

n – is the actual period of the operation of the whole equipment.

Statistical data on the elevator elements failure for 1 year of operation [18] are taken as initial data. The level of safety during the operation of the elevator for 1 year is calculated according to the initial data at 4 % wear of the elements.

E_{1yo}=(7*(1-0.04/25)+2(1-0.04/15)+16(1-0.04/12.5)+1(1-0.04/10)+6(1-0.04/5)))/36=0.885.

Similar calculations are performed for the periods of operation taking into account the replacement of the expired service life elements, the results obtained are grouped and presented in the form of the diagram (Fig. 3).

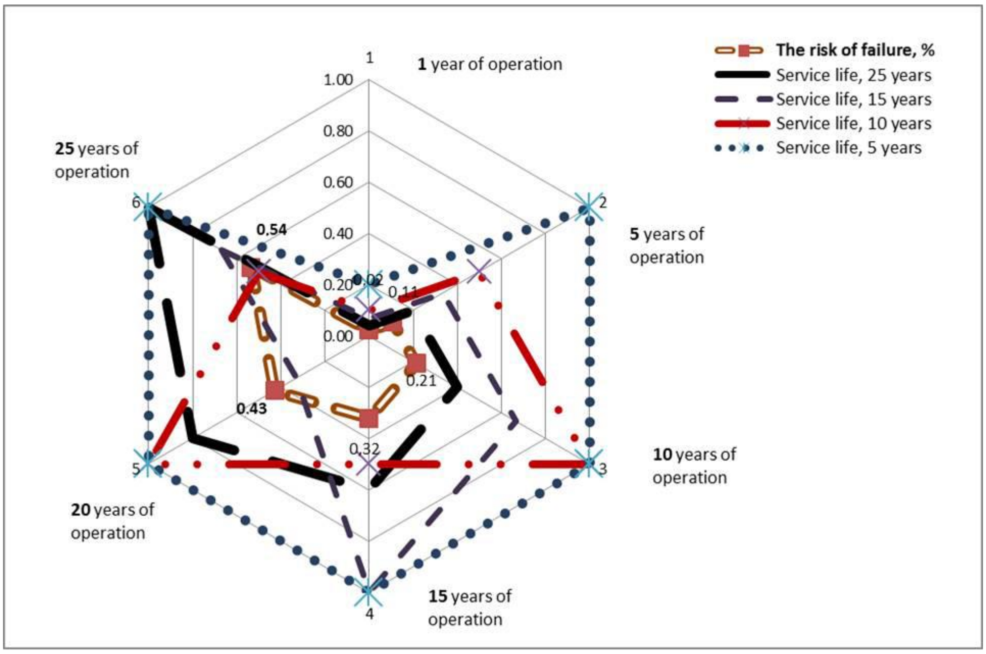

Figure 3 Diagram of the influence of the operating period of the elevator on the change in the probability of risk-failure

Table 3. The results of calculations of the influence of the operating period of the elevator on the change in the probability of risk-failure

The number of objects in the design	Resource	The period of operation					
1		1	5	10	15	20	25
7	25	0.040	0.200	0.400	0.600	0.800	1.000
2	15	0.067	0.333	0.667	1.000	0.330	0.670
1	10	0.100	0.500	1.000	0.500	1.000	0.500
6	5	0.200	1.000	1.000	1.000	1.000	1.000
The percentage of loss		2.14	10.71	21.42	32.13	42.83	53.54

The diagram shows the expired service life elevator components / elements replacement periods and the corrected service life parameter: the safety level 98 % is taken as a reference (this value may vary from 99.9 % to 95 % in accordance with TR CU Safety of elevators); for 1 year operation period the safety level is reduced from the stated 98 % to 88.5 %, which refers to the reduction of the safety level by 2.14 %; after a 10-year period losses increase up to 21.42 %; by the end of the operation period safety level decreases by 53.54 %.

Analysing the obtained results, it can be seen that the risk-failure value increases beginning from the year of operation regardless of the replacement of the time-expired elements. The wear of the remaining currently operated elements affects the risk-failure value.

Discussion

The suggested methodology allows performing similar assessment based on the results of the current condition records of the elevator elements within any period of operation, fixing the current performance parameters specified in the design model exactly for particular elevator [9, 10], which allows us to have quantitative value of the safety level in real time.

The social importance issue of safety insurance when operating vertical transportation has not yet attracted adequate attention of broad scientific camps [18, 22–26].

At the same time the available statistics data on the hazardous situations show the significance of the work performed. With high-rise construction, vertical transportation becomes an integral engineering system for ensuring the public comfort and safety.

The authors believe that the interdisciplinary, systematic approach to the conducted research ensures the stability of the public mobile movement ability when using vertical transportation and at the same time it reduces capital investments in the equipment operated [2, 10, 22, 25, 26].

Conclusion

1. The analysis of the scientific part as well as of the safety measures in the production sphere is performed.
2. Theoretical and practical inconsistency in the issue of taking safety measures in the production sphere has been identified from the ethical-social point of view.
3. It is revealed that the basic theories suggest a probabilistic computation of the risk parameters by modeling monotone logic functions, although in reality the systems are non-monotone functions.
4. It is suggested taking into account the duality of the computational arguments of the function of the engineering systems and expressing the risk-failure and safety parameters by Boolean variables using the example of vertical transportation. All these allow reducing errors in the development of possible hazardous situations scenarios.
5. The modified model of the cost calculation of time losses in non-production downtime of the elevators is suggested by recording the safety parameter quantitatively expressed by the factor of loss due to the elimination of the consequences of the abnormal or hazardous situation.
6. Characteristics of the elevators, escalators and passenger conveyors have been carried out for the risk and corresponding influence factors assessment.
7. The modified methodology for safety assessment of the elevator within the real operational period is worked out. The previous influence factors and the contribution of the event have been taken into account. The methodology allows us to make adjustments both in the conditions of technical operation and in the requirements for under-load operation of the elements ensuring safety without design improvements. It also allows ranging weight limits of the system elements integrally.
8. The example of the implementation of the modified methodology is given when determining the residual life of the elevator elements. The diagram of the effect of the operating period of the elevator on the change of the risk probability parameter is constructed.
9. The presented method of adjusting the service life parameter of vertical transportation according to the failure risk and safety criteria allows us to predict the safety of vertical transportation operations in accordance with the service lifetime as well as to identify the most problematic elements and to prepare a set of spare parts for restoring serviceability in advance.

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