Integrated technique of planning the capital repair of residential buildings and objects of transport infrastructure

Marina Dement'eva[1]

[1]Moscow State University of Civil Engineering, Yaroslavskoe shosse, 26, Moscow, 129337, Russia

E-mail: 7dem@mail.ru

Abstract. The paper presents the results of a comparative analysis of two fundamentally different methods for planning capital repairs of objects of transport infrastructure and residential development. The first method was based on perspective long-term plans. Normative service life were the basis for planning the periodicity of repairs. The second method was based on the performance of repairs in fact of the onset of the malfunction. Problems of financing repair work, of the uneven aging of constructs and engineering systems, different wear mechanism in different conditions of exploitation, absence of methods of planning repairs of administrative and production buildings (depots, stations, etc.) justify the need to optimize methods of planning the repair and the relevance of this paper. The aim of the study was to develop the main provisions of an integrated technique for planning the capital repair of buildings of any functional purpose, which combines the advantages of each of the discussed planning methods. For this purpose, the consequences of technical and economic risk were analyzed of the buildings, including stations, depots, transport transfer hubs, administrative buildings, etc when choosing different planning methods. One of the significant results of the study is the possibility of justifying the optimal period of capital repairs on the basis of the proposed technical and economic criteria. The adjustment of the planned repair schedule is carried out taking into account the reliability and cost-effectiveness of the exploitation process.

1. Introduction

The main task of exploiting buildings and objects of transport infrastructure is to ensure the safety and comfort of users, taking into account economically justified tariffs [1]. To this end, all types of exploitation activities should be planned competently. Since residential, administrative and production buildings (depots, stations, etc.) can be called a product of long-term consumption, capital repairs is the most important repetitive activity. The implementation of capital repairs not only prolongs the service life, ensures the reliability and energy efficiency of buildings, but also contributes to the renewal of the architectural appearance of cities. Therefore, the efficiency of capital repair planning has the most massive social influence.

When studying the problem of planning capital repairs of residential and industrial buildings in Russia was carried out a historical review of scientific and technical literature [2–6] and the legislative framework [7–9]. The results of the review showed that two main planning methods can be distinguished. In the first case, repairs are performed when the elements of the building reach their normative service life. In the second case, capital repairs are performed when the elements of building reach an inoperative technical condition. The results of a comparative analysis of the existing methods for planning are shown in figure 1.

Method of capital repair planning	According to the normative resource	According to the actual resource
Type of capital repair	According to the regulations	According to need
The purpose of capital repair	Prevention and elimination of wear and tear	Elimination of the arisen malfunction
The nature of the work of capital repair	Planned repairs and replacements	Search and elimination of threatening malfunctions
Terms, scope and composition of work of capital repair	Defined by perspective long-term plans	Defined by technical condition, cumulative wear and tear
Basis of planning of capital repair	Terms for the minimum duration of effective exploitation	Results of inspection of technical condition, analysis of applications of residents

Figure 1. Comparison of the characteristic features methods of planning for the capital repairs of residential buildings and objects of transport infrastructure.

In the conditions of centralized production and distribution of material and technical resources, financing of repair works was organized system of so-called planned preventive repairs [7]. Researches have established [10] that the timely restoration of building elements reduces the cost for the subsequent exploitation period due to the reduction of malfunctions, lower costs for eliminating these malfunctions and their consequences.

This method of planning was to ensure the planned guaranteed longevity, safety and comfort of the building. However, there were situations when some elements were replaced before the depletion of their actual resource. This reduced the economic efficiency of the exploitation process. Also, underfunding of other repair works led to a gradual accumulation of wear of residential buildings and objects of transport infrastructure.

Another problem was the lack of statistical data on the technical condition of the residential, administrative and production buildings (depots, stations, etc.). Only since 1990 after the development of the document [11] there were data on the emergency and dilapidated housing stock.

From the 90s of last century was a transition to fulfillment of capital repairs on necessity in the conditions of acute shortage of means in a municipal economy as well because of the formation of various forms of ownership [12, 13]. To perform repairs it was necessary to reliably know the time when they should be performed in order to maintain the structures and equipment in in operating state. But due to the fact that the service life is an accidental event, it is impossible to determine in advance the exact time for carrying out repairs with this planning method. Consequently, in most cases, the volume of repair work, the place and time of their conduct were probabilistic. The result was a reduction in the volume of capital repairs carried out and an increase of wear of residential buildings (figure 2). At the same time, statistical data on the technical condition of objects of transport infrastructure are still not being collected. Although they are objects of increased social responsibility.

The basis for the safe exploitation of buildings in this situation was the need to obtain reliable information about the technical condition of elements and equipment. For this purpose has been developed a monitoring system for the housing stock. This method of planning repairs is characterized by an increase in the time between repairs.

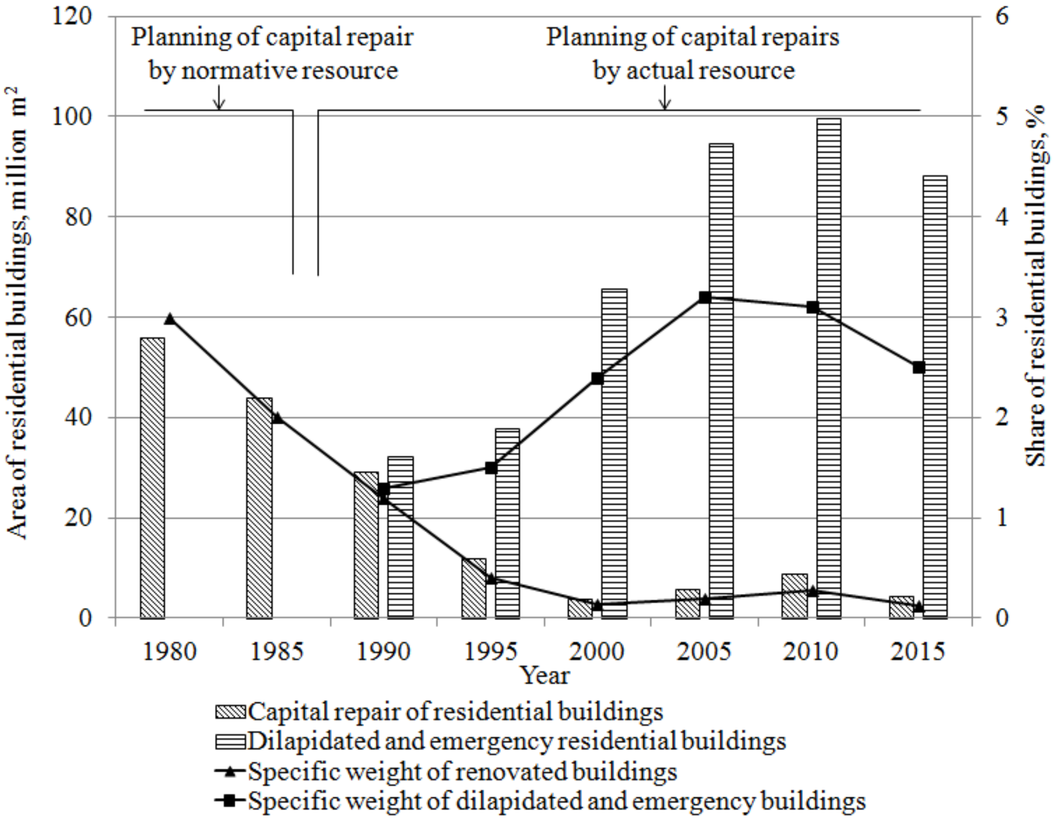

Figure 2. Capital-renovated and emergency housing at various methods of capital repair planning [14, 15].

On the other hand, the intensity of failures increases, security of use of the facility decreases, social discontent increases, and costs for eliminating the consequences of failures increase. In addition, demonopolization of housing and communal services and the formation of contractual relations have led to the emergence of a large number of frequently changing organizations for the management of real estate. Therefore, the absence of long-term obligations to owners reduced the interest in the quality performance of repair work.

In 2015 was restored the system for planning capital repairs of residential buildings, under which the owners of the building are obliged to organize and finance it [8, 16]. In this paper was studied the procedure for determining the timing and composition of work in the planning of capital repairs. It became obvious that the planning of capital repairs is still based on determining the physical wear and tear of the building, and the periodicity of the work is determined by the normative service life of the elements, presented in [17]. As a result of the analysis of the normative and technical documentation mentioned above were identified the following problems arising at the moment in the planning of capital repairs:

1. There were new series of houses, constructive solutions, new materials worked out. At the same time, the list of materials and structures in regulatory documents hasn't been updated for more than a decade. The project documentation doesn't contain data on their service lives. This doesn't allow you to effectively plan for capital repairs for objects of any functional purpose.

2. Modern multi-layered enclosing structures are often used for capital repairs of a building. They increase the energy efficiency of subsequent exploitation, but have low maintainability. In combination with the problem of insufficient quality of construction work, their actual service life is reduced.

3. There are no systematic observations of buildings and objects of transport infrastructure, their structures and engineering systems. This doesn't allow you to specify the service life in real conditions exploitation and justify the repair time for users who finance repair work.

4. Wear of the building is assessed based on the results of a expertise carried out by a specialized organization and requires material costs. However, in a number of cases the result is a confirmation of the obvious fact that everything is safe and no repairs are required.

5. The methodology for assessing wear is based on a visual survey and is of a stochastic nature, related to the qualifications of experts and the human factor. An important decision on the need to perform capital repairs is made on the basis of personal opinion.

Studies on the problem of capital repair planning have shown that at the moment the methods its planning are outdated. Therefore, the purpose of this study was to develop the general provisions of an integrated technique for planning the capital repair of residential buildings and objects of transport infrastructure.

2. Materials and Methods

The object of the study in this paper were the existing methods for planning the capital repair for objects of any functional purpose, for example residential buildings. The subject of the study were the principles of optimizing the methods of capital repair planning, taking into account the modern needs of society. To successfully solve the set goal, an algorithm for research was determined, which took into account the interconnection of technical and economic problems of the city economy (figure 3).

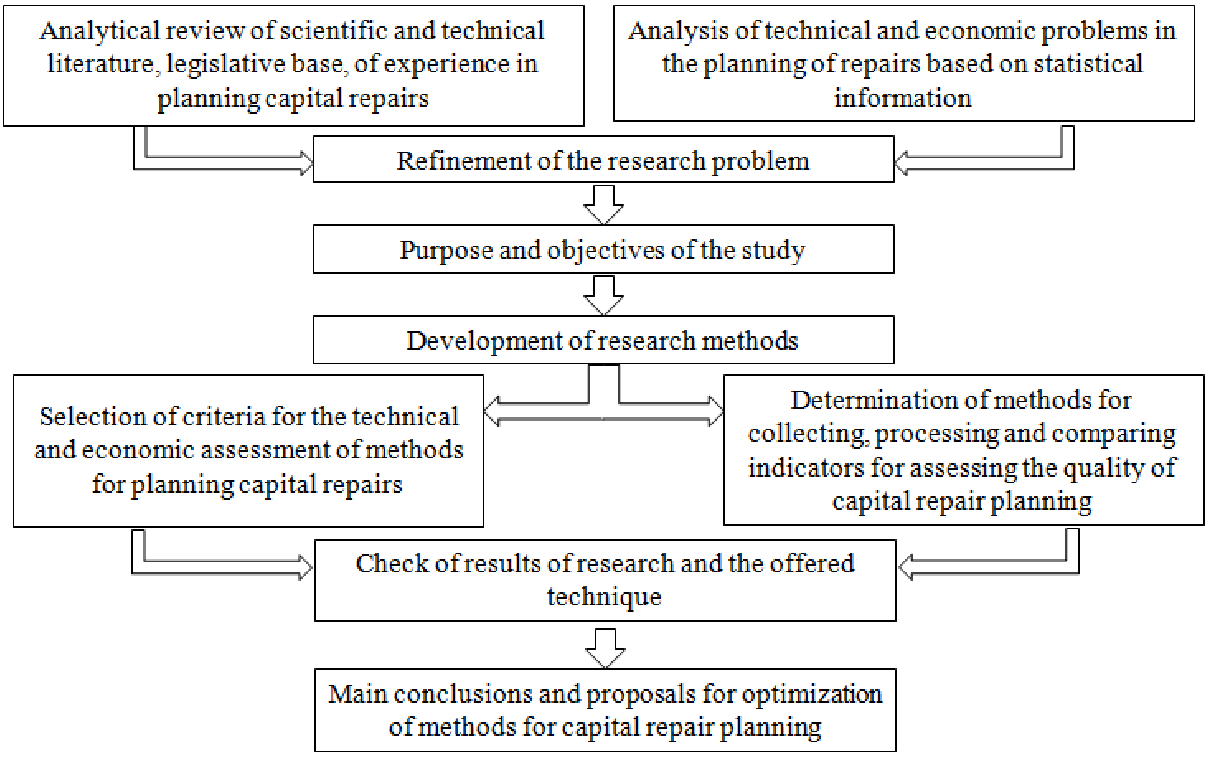

Figure 3. Block diagram of the methodological features of the study.

The result of making management decisions in choosing different methods of repair planning are consequences with different types of damage and severity – risks. In this study, a qualitative analysis method was used to determine the main risks and their characteristics. Based on the above, the following assumptions were made:

1. Risks have one source – the chosen method of repair planning.

2. Ultimately, all the consequences of risks lead to the technical impossibility and/or economic inefficiency of the exploitation of a single element or building as a whole.

These assumptions formed the basis for the methodology of research and the determination of criteria for the technical and economic comparison of existing methods for planning the capital repair of residential buildings. Previously, various indicators were proposed to assess the quality of planning and performance of works [18–20]. In this paper, the following criteria are proposed for evaluating the effectiveness of repair planning:

1. Number of repairs per time unit – the intensity of repair work *I*.
2. Exploitation costs per unit of time – exploitative specific costs *C*.

The intensity of repair work can be determined by statistical methods, and also based on the calculation of the mathematical expectation of the average lifetime of a building element as a random variable:

$$I = \frac{1}{\mathrm{E}[T]} \quad (1)$$

where E[*T*] is the mathematical expectation of the average period between the restoration points of the building element.

When determining E[*T*], it is necessary to take into account the likelihood of planned and emergency repairs, as well as the probability of finding the building element in a faulty condition until the failure is detected:

$$\mathrm{E}[T] = \int_0^\infty \overline{F}(t)dt + T_p \int_0^\infty \overline{F}(t)G(t)dt + T_e \int_0^\infty F(t)\overline{G}(t)dt + \int_0^\infty F(t)dt \quad (2)$$

where $\overline{F}(t)$ is a probability of failure-free exploitation of the element in a time greater than *t*; T_p is the average duration of planned repair; $G(t)$ is a probability of effectuating a planned repair for the period *t*; T_e is the average duration of emergency (unforeseen) repair; $F(t)$ is a probability of failure of the element in time *t*; $\overline{G}(t)$ is a probability of effectuating a planned repair for a time greater than *t*.

The first term determines the duration of the element's working state. The second term determines the duration of the planned repair. The third term determines the duration of the emergency repair. The fourth term determines the duration of the element in the state of latent failure.

Exploitative specific costs is a limit of the expenses, referred to an operating time of an element:

$$C = \lim_{T \to \infty} C(T) = \frac{\sum_{i=0}^{n} c_i T_i}{T} \quad (3)$$

where c_i is the specific loss when the element is in state *i*; T_i is the random time of finding the element in state *i*; *T* is the total duration of exploitation of the element.

Let's exploitative specific costs through shares of time of a finding of an element in various technical conditions for the considered period τ:

$$C(\tau) = \frac{c_p T_p + \left(c_e T_e - c_p T_p\right)F(\tau) + c_f \int_0^\tau F(t)dt}{\int_0^\tau \overline{F}(t)dt} \quad (4)$$

where c_p, c_e and c_f are, respectively, costs for planned repair, costs for emergency repairs and costs when the element is in an inoperative condition; $F(\tau)$ is the probability of failure at time τ.
Differentiation of this equation makes it possible to obtain roots that determine local minima of exploitative specific costs and determine the optimal period for carrying out capital repairs.

3. Results

One of the objectives of the study was to perform a comparative analysis of technical and economic risks. Technical risk is associated with the threat of failure of elements. Economic risk is associated with material losses of different origin.
The results are systematized and presented in table 1.

Table 1. Qualitative analysis of the consequences of risks in different methods of capital repair planning.

Risk group	Planning of capital repair by normative resource	Planning of capital repairs by actual resource
Technical risk	Reducing the time between repairs Underestimation of the technical resource of building elements during preventive repairs Increase in the volume of repair preventive works	Increase in the flow of failures Decrease in safety, comfort, durability of a building Increase in premature wear of building elements Lack of long-term planning and supplys
Economic risk	Increase in costs due to underestimation of the residual life of building elements Increase in costs for comprehensive repair work	Increase in costs for eliminating failures Increase in costs for eliminating the consequences of failures

To solve the task set in the work was proposed an integrated technique for determining the optimal time for capital repairs the building. The technique combines the advantages of each of the repair planning methods. It allows you to take into account the actual technical condition of the building, ensure safe exploitation and optimize exploitative costs. The essence of the technique is as follow (figure 4):

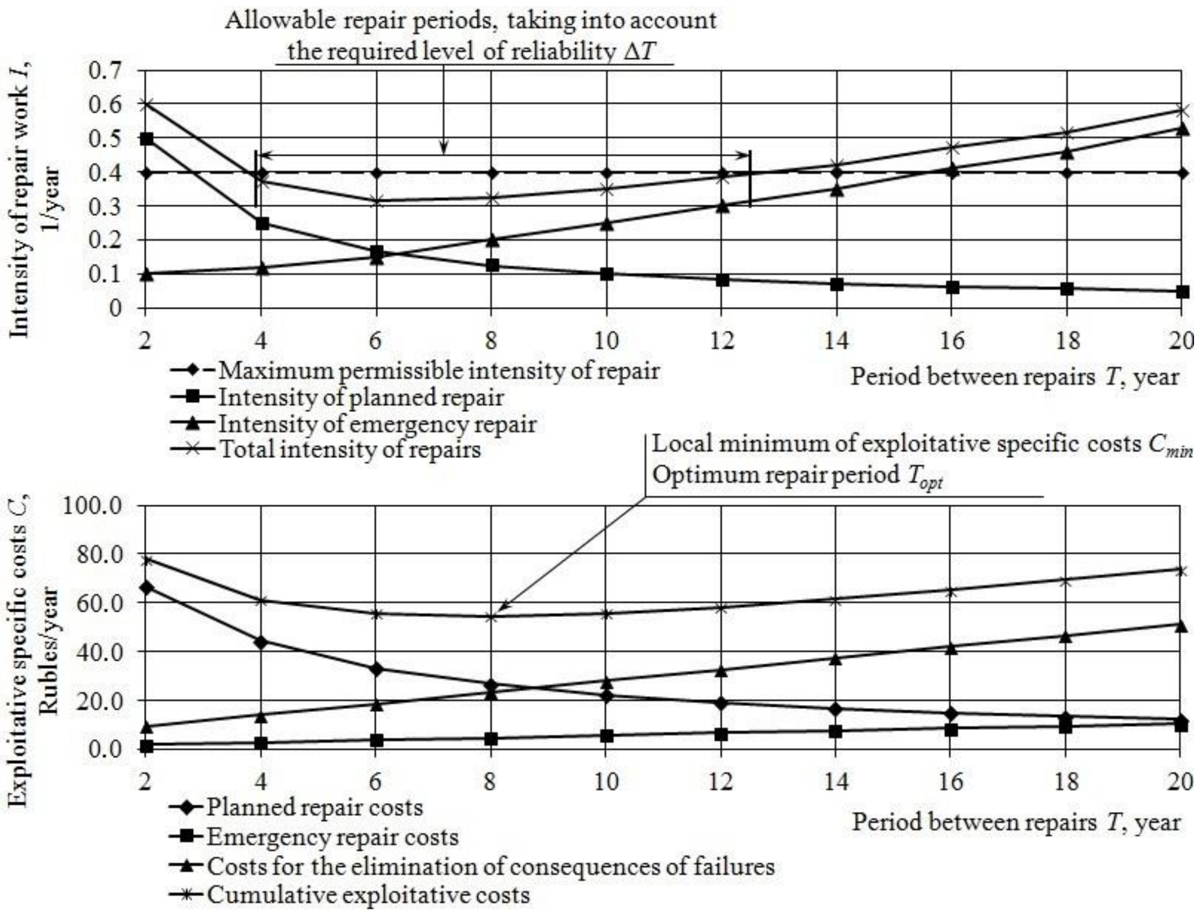

Figure 4. Dependence of intensity of repair work and exploitative specific costs from the period of capital repairs.

1. At the first stage, the intensity of repair work I is determines as an indicator of the quality of exploitation. It will change at different periods between repairs. For a small period, the frequency is affected by the number of planned repairs. For a long period, the frequency is affected by the number of emergency repairs.

2. In the second stage determines the interval ΔT at which the calculated repair frequency doesn't exceed the normative values.

3. In the third stage determines the value of the exploitative specific costs C in this interval.

4. In the fourth step determines the period T_{opt} with the least exploitative specific costs from the selected interval.

The proposed integrated technique is focused on the overall definition of the intensity of repair work and exploitative specific costs and is aimed at minimizing costs while ensuring the required quality of the building.

The principles of optimizing the methods of capital repair planning, taking into account the modern needs of the society, are based on the specification of the period for carrying out capital repairs taking into account the cost, technical condition of the building and the risk of failure of its elements.

4. Discussion

Risk management has made it possible to identify problem situations in the planning of capital repairs of residential buildings and objects of transport infrastructure and the direction of further research. It was found that the scope, composition and cost of work depends on the method of planning the repair. The obtained results showed that it is difficult to specify the service life, to normalize them due to the availability of a variety of materials, products, and also due to very different conditions exploitation in the vast territory of our country. Therefore, it is necessary to develop a methodology for predicting service life, depending on the various conditions exploitation and the technical condition of the building at the current time (figure 5).

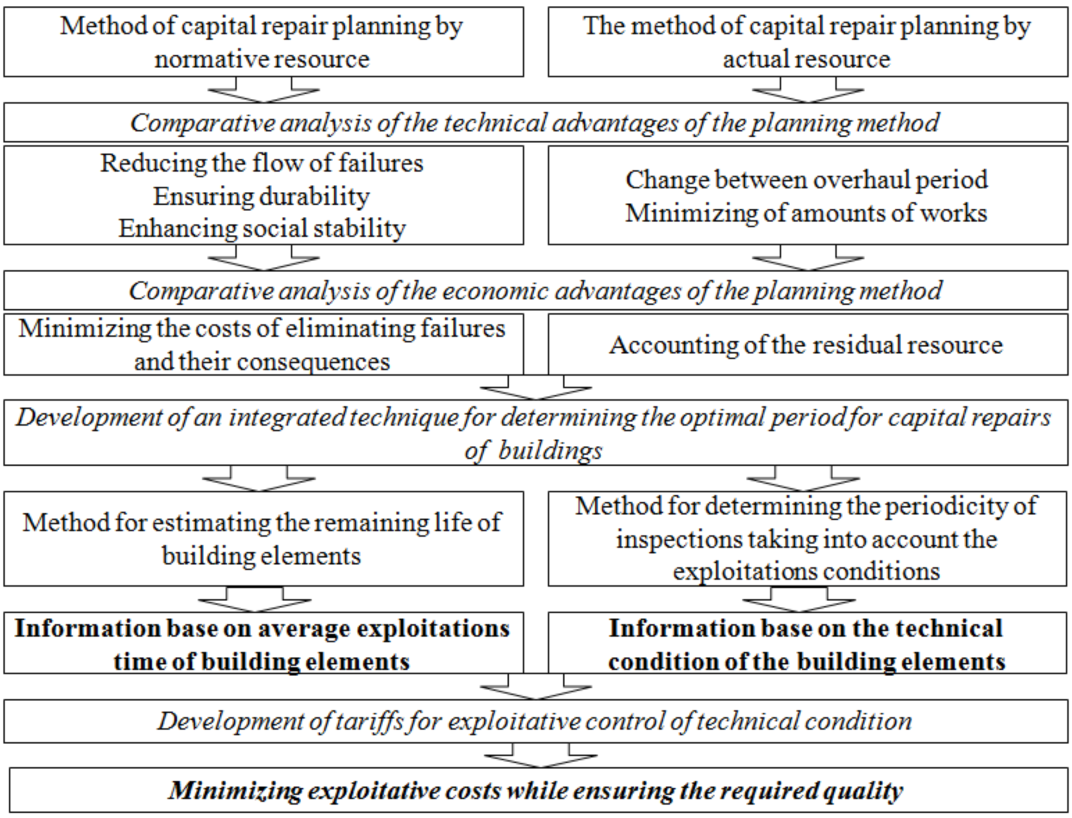

Figure 5. General provisions of the integrated technique for planning the capital repair.

Also, the results of studies have shown the need for visual inspections or instrumental surveys during the monitoring of the technical condition of the building [21–23]. These measures have costs and therefore require an economic justification.

In the future in order to implement the integrated technique it is necessary to solve economic issues related to the lack of officially approved tariffs for inspections, technical condition monitoring, maintenance, emergency repairs. It is also necessary to solve technical issues related to forecasting the average operating time of elements before failure in view of conditions exploitation and technology for assessing the technical condition of building elements.

5. Conclusions

To solve the task set in the work, the following tasks were solved:

- Historical analysis of methods of capital repair planning in our country;
- An overview of the factors was carried determining the order of appointment of repairs;
- An algorithm was developed for studying the problems of capital repair planning;
- A qualitative analysis of the consequences of risks was carried out for different methods of capital repair planning;
- Criteria was proposed for evaluating the efficiency of capital repair planning;
- General provisions was proposed of the integrated technique for determining the optimal period for capital repairs of the building;
- An example of calculation was given of the optimal period of capital repair planning.

The results obtained in the work allow to carry out the feasibility study of the periodicity and conditions for the assignment of capital repairs. Considering the whole set of consequences of risks, it was established that the main element of decision making in the planning of repairs is exploitative control. Therefore, additional research is needed on the methods of appointing surveys of the buildings, including stations, depots, transport transfer hubs, administrative buildings, etc.

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