Article
The Technical State of Engineering Systems as an Important Factor of Heat Supply Organizations Management in Modern Conditions

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Abstract: This article examines the features of the heat supply organizations (HSO) anti-crisis management, which has become relevant due to the pandemic in the spring of 2020. It is noted that the spread of coronavirus and the related economic problems had a negative impact on the sustainable development indicators of both countries and organizations. HSO, which are rarely considered in modern publications, are positioned in the study as the most important part of the economy of any country, on which the future stabilization of the economic situation among heat consumers depends. This study made it possible to draw a conclusion about the strengthening of the HSO engineering systems technical state role in the anti-crisis management of these organizations. The study summarizes and presents the main characteristics of the heating networks technical condition and systematizes all types of diagnostics that are encountered in practice. The characteristics of HSO management choices of the technical state monitoring methods is given. The authors propose a generalized model of the diagnostic methods choice, taking into account the sustainable development of a specific HSO. Perspective approaches to the improvement of the HSO heat supply systems state are determined, which will ensure the development and increasing reliability of urban infrastructure in the context of achieving sustainable development goals.

Keywords: anti-crisis management; heat supply organizations; management tools; technical state; diagnostics; modeling; digitalization

1. Introduction

The main global trends determining the development of all sectors of the economy in recent years have been focused on achieving sustainable development goals and digital transformation. In 2020–2021, a new factor appeared—the pandemic, which had a significant impact on the economy, affecting, to a greater or lesser extent, all industries. In this regard, the question of searching for new solutions, which, by their purpose and meaningful characteristics can be considered anti-crisis, but which, at the same time, make it possible to maintain a focus on sustainable development. In the context of this article, sustainable development of economic systems is understood as their long-term development in the changing conditions of the external and internal environment, balanced in terms of economic, social, and ecological indicators, which allows them to maintain their competitiveness.

In particular, the approach to the functioning of the heat supply industry, which in many countries is one of the life-supporting industries, requires a significant revision.
Obviously, the issues of ensuring sustainable development in the heat supply industry that require research, are concentrated to the greatest extent where their growth was observed even in the “pre-pandemic” period. Of course, the forecast of energy consumption is also important, which determines the possibilities within which realistic tasks of planning the development of the energy supply system will be set [1].

Many authors also raise the issues of the influence of the energy complex on the ecological and socio-economic development of the territory as one of the links of sustainable development [2–4].

In Russia, the problematic issues of heat supply development are associated with the growing wear of heat-generating and heating network equipment in conditions of insufficient investment, which, during the pandemic were further reduced. On the one hand, in the context of weak external demand, the decline in mining, including resources for generating heat energy, continued (−14.2% in June after −13.5% in May 2020 [5]). On the other hand, the transition of a large number of enterprises to remote work significantly affected the demand for heat energy. The Association “Council of Energy Producers” of the Russian Federation reported that the level of payment for heat energy was 3.2% less than for the same period in 2020, while a crisis decrease in the volume of payments was recorded among the population—by 13.3%, as well as managing organizations—by 6.3%. The accumulated receivables accounted for 30% of all heat energy that was consumed in 2020. As a result of the growth of non-payments, the financial situation of energy supply organizations is significantly deteriorating [6].

Similar situations of crisis in energy supply, which directly or indirectly affected its organization, were observed not only in Russia, but also in many other countries around the world. This determined the need to look for the “main link” in providing anti-crisis measures, which would make it possible to maintain the trend towards sustainable development in the face of a decreasing amount of resources that is irrational to “scatter”. Therefore, all areas of activity of energy supplying organizations were analyzed and, according to the Pareto principle, the most effective factor in a crisis situation was determined—the technical condition of engineering systems and their associated reliability and efficiency.

It is important that, in world practice to date, there are various options for organizing heat supply, ranging from completely centralized (countries of the post-Soviet space—Uzbekistan, Tajikistan, Kazakhstan, etc.), an intermediate option—combining decentralization and centralized systems (for example, USA, Canada), to completely local options for organizing heat supply in some European countries. However, in recent years, the focus on achieving sustainable development goals has shifted the priorities for the development of energy systems in many countries. In the context of the prevalence of decentralized schemes, the transition to centralized systems which can significantly save resources becomes relevant. The main arguments for this transformation in technical terms are:

- Increasing the energy efficiency of heat production through the use of combined heat and power generation. Thus, the program documents that are adopted in a number of countries [7,8] suggest a significant increase in the share of combined heat and power generation, which is planned to be achieved through financial, technical, and information support for the introduction of cogeneration technologies;
- Increasing the energy efficiency of heat consumption [9–11], which can be achieved on the basis of technical norms and standards in the design and construction of heat supply facilities, mandatory energy certification of buildings and structures, and other measures. In the context of digital transformation, it is important to introduce intelligent systems for collecting data on the actual technical condition of heat supply systems and heat consumption.

In these circumstances, the “common denominator” for all variants of the heat supply industry organization is the technical state of the heat supply systems and their elements, which we considered in this study using the example of Russia and other countries with similar characteristics of heat supply systems. In practice, this means the need to maintain
the technical condition of engineering systems on the basis of an objective assessment of the technical resources, which, on the one hand, guarantees the reliability of heat supply to consumers, and, on the other hand, will allow industries to get out of the crisis situation by reducing operating costs and improving the energy efficiency, thereby contributing to the sustainable development of the organization. The main focus in achieving the necessary balance is the technical state of engineering systems, the objectivity of the assessment plays a significant role in the process of developing new anti-crisis management tools for HSO. The issues of organizing technical system diagnostics have repeatedly become the subject of discussion, however, did not come to the fore, so at present it is important to determine a new methodological approach to its organization which makes it possible to establish the best configuration of technical diagnostic tools to ensure the stability of the HSO operating in the conditions of the changed nature of energy supply to consumers.

2. Materials and Methods

Intervention studies involving animals or humans, and other studies that require ethical approval, must list the authority that provided the approval and the corresponding ethical approval code. In this study, management is considered in conjunction with the issues of improving the quality and reliability of the heating networks that are operating and reducing the HSO costs that are associated with carrying out repairs through the development of an integrated methodological approach for organizing technical diagnostics of heating networks. Until now, power supply organizations have relatively rarely raised the question of the importance of technical diagnostics and a detailed analysis of its impact on reliability and efficiency. Principles of the organization of diagnostics have not been reviewed for many years for various reasons.

Diagnostics of any technical objects includes the following functions:

- An assessment of the technical condition of the object;
- The detection and localization of faults;
- Forecasting the residual resource of the object;
- Monitoring the technical condition of the object.

The activity of HSO is of a pronounced seasonal nature: during the heating season, it is required to provide reliable and quality heat supply to consumers at established prices, and to carry out the necessary volume of repair and restoration work on heating networks and generating capacities outside this period. From the 70s of the last century, the minimization of costs for diagnostics of technical condition in the district heating systems in Russia and the countries of the post-Soviet space was ensured by carrying out so-called pressure tests, i.e., determination of the technical condition of pipelines on the basis of their hydraulic testing under high pressure. The sections of the heating network, the technical condition of which did not allow them to withstand the load and led to the rupture of the structural material, were taken out for repair. The average efficiency of this method is 92%, but at the same time, information about “non-ruptured” pipelines was not available for obvious reasons. It was impossible to predict the upcoming repair costs and make an attempt to optimize them, which is especially important in the face of reduced financial resources.

The hydraulic test method is effective only if this decision is considered in the short term and provides a minimum amount of information for making management decisions. While, from the perspective of long-term planning in the context of overcoming crisis situations and focusing on the sustainable development of HSO, the management of this organization needs to implement a newer, more systematic approach to identifying the technical state of heating networks. Considering the strengthening of the engineering systems technical state in modern management, many HSOs began to use other management tools in combination with hydraulic tests, namely conducting a planned basic diagnostic of the engineering systems technical state using non-destructive and destructive testing methods. The information that are obtained as a result of such methods makes it possible to provide the possibility of long-term forecasts of the engineering systems technical state,
to determine the prospect of sustainable development of TCO and to balance it according to a set of indicators.

However, it is not always possible to carry out such diagnostics on their own—equipment and personnel of appropriate qualifications are required, which makes it necessary to bear the costs of outsourcing them. Therefore, the management of HSO needs to base the choice of a set of methods and diagnostic tools on an approach to its organization that allows for the minimization of resources for their provision while ensuring the required quality of diagnostics.

The research methodology that is adopted by the authors that is aimed at forming a new methodological approach to the organization of diagnostics, is based on the implementation of four successive stages (Figure 1). Here, we describe in more detail the materials and methods that were used by the authors in the framework of each of the stages of the research sequence presented that is above.

Figure 1. Scheme of the study that is presented in this article.

At the first stage is the method of analyzing the current regulatory and legislative framework of Russia and other countries with similar characteristics of heat supply systems. The regulatory and legislative framework in any country acts as the basis for the formation of a diagnostic system, being both a “starting point” and a set of mandatory conditions that diagnostics must meet. Therefore, a comparative analysis was carried out in the context of a number of countries. It should be noted that a detailed analysis of the structure of the countries’ legislative documents on energy supply and an analysis of their provisions made it possible to state their significant differences, but at the same time confirmed important common characteristics that determine the possibility of universal solutions for organizing diagnostics:

- Organizational and economic factors of the HSO functioning which determine the engineering systems structure and composition, their configuration on the territory of deployment, the operation requirements, as well as the conditions for the heat energy supply in terms of its quality, timing, and reliability;
- Technical factors of the HSO functioning, including the requirements for the technical state of engineering systems that are operated in the process of heat energy generation, transportation, and distribution; methods for identifying this state; as well as a list of the generated information and ways for its interpretation for making management decisions.

At the second stage, a review of the materials of scientific and technical achievements and HSO diagnostics practice in the field of destructive and non-destructive testing methods of the heating networks pipelines state was carried out. At this stage, the authors also encountered completely different experiences of the countries that were studied, establishing that the energy supply organizations of the “post-Soviet” space, where the heat supply systems are more accident-prone, have advanced to a greater extent; however, experiences
vary greatly even within the same country. Therefore, an analytical approach was applied to the comparison of destructive and non-destructive testing methods based on statistical studies of factual data of the intensity of defect development processes, as well as on the results of their diagnosis by various methods.

The development of an indicator system, which constitutes the content of the third stage of the research, was formed on the basis of regulatory materials of Russia and other countries with similar heat supply system characteristics using a grouping method which made it possible to follow the author’s provisions that related to the technical state of the engineering systems and sustainable development of TSO:

1. Ensuring the reliability of heat supply in accordance with the requirements of technical regulations. This means that the contractual obligations of the HSO to the consumers oblige the supplier to do this while observing the safety of the supply processes and ensures the requirements for the quality of heat energy and heat carrier;
2. Ensuring the efficiency [12] of the generation and transportation of heat energy, which implies the elimination of unproductive resource losses due to the technical condition of engineering systems, and, in the future, investment in the transition to digitalization of operation and usage of energy efficient structures and technologies;
3. Ensuring the environmental safety [13] of heat supply, which in the current situation remains one of state priorities for managing the industry and requires the analysis of the technical state of engineering systems from the standpoint of environment protection measures;
4. The priority development of district heating systems on the technological basis of cogeneration [14], taking into consideration the economic and territorial characteristics of the country;
5. The achievement of economically justified profitability of the current activities and investments of the HSO, which forces the management of the HSO to bring into the special planning zone the issue of renewing worn-out engineering systems;
6. The observance of non-discriminatory and transparent conditions for the implementation of consumer relations in accordance with the requirements of antimonopoly legislation [15], the basis for which is the technical capabilities of connecting all consumers to the HSO engineering systems.

It should be noted that the above provisions fully meet the objectives of the Russian Federation that are aimed at achieving the sustainable development goals and are universal in terms of regulating these issues in other countries.

To select the means of technical diagnostics, the use of which will ensure the listed requirements, the authors proposed a number of technical and economic indicators, which are presented in more detail in the “Results” section.

At the final fourth stage, the systematized research materials on the compared methods of diagnostics were used and the method of mathematical modeling was applied to develop recommendations for HSO for choosing the optimal set of technical diagnostic methods, the use of which has not previously been presented in studies. Admittedly, the choice of diagnostic tools should be the responsibility of managers, whose subjective opinions prevailed in the selection. At present, when the crisis phenomena in the economy have fully manifested themselves, decision-making should be formalized and allow comparison of options that are based on quantitative assessments, which will contribute to the rational allocation of resources for both diagnostics and repairs of heat supply systems based on its results. This made it possible to develop a generalized managerial decisions model which forms the basis of a new methodological approach to the diagnostics organization.

3. Results

The study of the regulatory framework that was conducted by the authors showed that, depending on the territory and range of coverage, the regulatory framework in any country is divided into two levels: country and sectoral levels. The analysis established two opposing positions—strict control by the state and its almost complete absence. A
distinctive characteristic of the Russian Federation, as well as several other post-Soviet countries (Belarus, Uzbekistan, Kazakhstan), is the presence of uniform requirements for ensuring the industrial safety of heat networks and its mandatory state control. Separate documents of an industry nature that were developed quite a long time ago, contain requirements for monitoring the technical condition of heat networks, which differ depending on the availability of the structural elements being monitored—accessible and not directly accessible parts of engineering systems. The analyses that were carried out by the authors of the practice of fulfilling these requirements for diagnostics by HSO showed their low productivity, primarily due to the focus on outdated methods for monitoring the technical condition of heating networks and the lack of consistency.

The regulatory and legislative framework of other foreign countries defines a fundamentally different procedure, unlike the Russian Federation, for ensuring control of the state of the heat network, which should be systematically ensured at all stages of the life cycle of centralized heating systems, including design, the manufacture of basic materials and equipment, construction, and operation. The subject of control is also different from domestic practice due to the presence of risk factors for disruptions in the operation and heating network and the strength of their impact. At the same time, HSOs without the presence of a specialized state technical control body are fully responsible for the quality of functioning of heat networks based on their own approach to assess their technical condition of existing heat networks.

In general, it should be noted that, according to data that were published in the open press (articles, reports), in modern conditions, the assessment and forecasting of the technical condition of existing heating networks and “life extension” is carried out according to internal regulations that are developed by HSO personnel; a universal model for assessing the technical state of thermal networks does not exist now. Thus, it can be stated that the regulatory and legislative framework of all countries in the field of methods for monitoring and evaluating heat networks leave a sufficient space for their specification. At the same time, the analysis made it possible to identify a significant set of requirements, both mandatory and recommendatory, that can be used to improve diagnostics.

In practice, according to data from open sources, in the EU and the USA, for diagnostics of existing heating networks, built-in alarm systems for the dampening of the insulating layer are mainly used, and thermal imaging aerial photography is carried out in the infrared range. Also, continuous monitoring of the coolant leakage at the branches of the main networks and at consumers is carried out. Instrumental diagnostics of heat networks by methods of non-destructive and destructive testing in the EU and the USA are carried out mainly under the control of state-accredited bodies (experts) at all stages of the construction of heat networks, from checking components to commissioning. At the same time, the range of methods for monitoring the technical condition of pipelines of existing heating networks is limited; at the stage of operation, it is assumed a priori that the pipelines that are put into operation are highly reliable. Accordingly, approaches to organizing the operation of pipelines and monitoring their condition do not imply the presence of problematic situations that are associated with the poor quality of work that is performed at the stage of pipeline installation and the use of low quality materials and low quality network water, which quite often occurred in the Soviet and even post-Soviet period in domestic practice. At the same time, the argument that in these countries there is no need for modern diagnostic methods, for example, in-line diagnostics, would be untrue.

In the countries of the post-Soviet space, a very diverse pattern of using various diagnostic methods has been accumulated, but at the same time, the amount of data are not enough for a full-fledged comparative analysis, since each HSO mastered those diagnostic methods that corresponded to its capabilities. Nevertheless, experts believe that the most promising in terms of practical application are the methods of in-line diagnostics. Despite the fact that today the existing methods of in-line diagnostics are not able to give exact information about the actual state of the pipeline and its working life, their reliability is at the level of 75–80%, which is 1.5–2 times higher than the reliability of other non-destructive
testing methods. Thanks to the improvement of the method of in-line diagnostics and non-destructive testing modules, as well as the development of new instrumental methods for monitoring pipelines that are based on the modern development of technical means, it will be possible to replace hydraulic tests for diagnosing heating network pipelines with non-destructive testing methods. \[16\]

The study of the engineering systems technical state factor in the anti-crisis management of HSO made it possible to form a new management model in the field of production processes of the organization, which assumes the provision of the maximum possible efficiency of the technical diagnostics methods application. We have identified two conditions that play a decisive role in decision-making:

- The requirements for the content of information that allows obtaining objective data on the heating networks technical state, which can be used for heating network repair planning based on the selection of sections that require restoration measures.
- The selection of technical diagnostic methods that allow the obtaining of information of the required quality while minimizing resources for their use considering a large number of technical diagnostic tools operating on various technical platforms.

Analysis of the operational features of heating networks, which determine their technical state, made it possible to determine a list of the necessary characteristics of heating networks structural elements (Table 1). They must be fully identified on the basis of a set of diagnostic works to make necessary management decisions.

**Table 1.** The required diagnosed characteristics of heating networks.

| Heating Network Constructive Elements | Diagnosed Characteristics |
|--------------------------------------|---------------------------|
| Pipelines                            | - Detection of metal discontinuities, as well as dents, corrugations, edge displacements, etc., on the inner and outer surfaces of pipes, including welds;  
- Localization of defects along the length of the pipeline  
- Identification of places of stress-strain states;  
- Identification of leaks;  
- Measurement of pipe wall thickness and metal hardness;  
- Determination of pipeline geometry defects;  
- Determination of the pipe–ground potential to identify the zones of influence of stray currents. |
| Building structures                   | - Determination of the state of protective building structures of channels and chambers and drainage (if any);  
- Determination of the temperature and humidity conditions of the air in the channel and assessment of the heat losses;  
- Determination of the technical condition of siphons, roads and railways crossings and other structural elements;  
- Assessment of the condition of supports, fasteners and other structural elements of channels. |
| Insulation                           | - Determination of the integrity of the insulation structure of the heating network,  
- Wetness. |

To determine the most common types of defects that are detected by technical diagnostics, an analysis of damage statistics on heating networks of the Russian Federation was carried out and generalized based on data that were published in open sources by the authors of the article and other researchers.

To characterize the information that was used and its processing in the study, it should be noted that, for several decades, the authors have been conducting a study of statistical data on the heat networks operation while adhering to several conditions that provide a significant meaning for the conclusions. These include the following conditions that apply to the entire sample:
- All types of heating network layouts that were used in practice are considered: both ground and underground layouts;
- Accounting is carried out in the context of all types of underground layouts, from channel-less layouts to combining heat networks and other engineering systems in collectors;
- All the main pipe diameters of heating networks are considered, from the smallest diameter of 50 mm to the maximum diameter of 1400 mm;
- The observation period was multiple replicates of a one year period, during which there is a heating season and a season when heating networks are not in operation, during which current repairs and pressure testing that are described above are carried out;
- The data are recorded in relation to the age of the heating networks in the annual context; the age of heating networks was calculated from the year of commissioning, measured in years.

The results of the analysis are presented in Figure 2. While during the study, it was not always possible to consider the full dataset according to all the listed requirements, the patterns that were obtained in certain analytical data slices, for example, as in Figure 2, give practically similar results, which are discussed in more detail below.

![Figure 2. Distribution of causes of damage in backbone networks for the period from 2015 to 2020.](image)

It can be noted that the largest number of items are attributed to the technical condition of the heating network pipelines, which is confirmed by numerous studies that reveal the main reason for the deterioration of the technical condition of the heating network—external and internal corrosion of the metal [17]. According to research by the authors that was carried out on the example of the largest HSO of Russian megalopolises and correlated with the data of other researchers, the deterioration of the technical condition of heating networks due to external corrosion and electro-corrosion accounted for more than 50% of all cases, while internal corrosion accounted for 38%. The rest of the recorded cases of deterioration in the technical condition of heating networks, which was about 10%, was due to all other types of reasons. This guided the authors to search for those diagnostic configurations that make it possible to identify, in a priority manner, such reasons for the decline in the technical state of engineering systems.

A comparison of methods for the heating networks technical state monitoring should be carried out within the framework of three main blocks of work:

- As part of the preliminary block, a preliminary overview of the control methods that were available for use and included in the review was carried out. At the same time, the collected data were checked and their preliminary analysis for any method was
carried out from the standpoint of the reliability, relevance, and its completeness for comparison;
- As part of the analytical block, the comparison of control methods and the retrospective data analysis on the main defects of heat pipelines was carried out, according to which the specifics of the controlled parameters and states were identified. A detailed analysis of the two main groups of control methods—non-destructive and destructive—was carried out, taking into account the significant differences in the consequences of their use regarding the integrity of the heating network;
- As part of the recommendation block, on the basis of a set of comparison indicators, the definition and justification of the best methods for monitoring the technical condition of heating networks was carried out.

The research scheme is shown in Figure 3.

Figure 3. Scheme for conducting a comparative analysis of methods for technical diagnostics of heat networks.

Let us concretize these blocks based on the obtained research results. To carry out the work of the preliminary block, all the types of diagnostics that were encountered in practice, presented in Figure 4, that were differing in technical platforms for their implementation, were systematized.

They can be positioned as a universal classification of diagnostic methods, which is recommended by the authors for analyzing the conditions and possibilities of obtaining data for assessing the engineering systems technical state depending on the chosen technical platform for their implementation.

Within the framework of the work of the analytical unit, the comparative analysis of methods of destructive and non-destructive testing, including methods of external and in-pipe diagnostics of heating pipelines, was carried out using indicators that most reliably characterize each individual method. In the study, the following non-economic indicators and comparison parameters are suggested—the "method error" that was declared by the manufacturer of the equipment that was used for diagnostics by non-destructive and destructive methods, as well as the application scope of each of the analyzed methods.
However, this does not give an unambiguous answer to the question of the choice of diagnostic methods, but only supplements the previously obtained materials regarding their features.

![Diagram of diagnostic methods](image)

**Figure 4.** Methods that were used for complex technical diagnostics of heating networks.

For the conclusions to be correct, it is necessary within the framework of the recommendation block to reduce the various indicators to an integral indicator. According to expert estimates, the most universal is the indicator of the economic effect from the use of each individual method.

The authors proposed a general model for choosing a complex of technical diagnostic methods, which provides the ability to make decisions on development in the long term, balanced in all the considered indicators.

To achieve various goals of HSO management (ensuring maximum diagnostics coverage of heating networks, obtaining the most accurate result with respect to “pointwise” selected objects), it is necessary to use different, but at the same time interrelated optimization criteria for each of the established goals. The research that was carried out by the authors of HSO management priorities with various degrees culture of diagnostics in various management situations, allows us to suggest the following positions for consideration:

1. Ensuring the maximum diagnostic coverage of heating networks as expressed by the total length (L), is a typical situation for HSO, which has a large number of heating
networks with a long service life. The maximum length of the diagnosed heating networks, km, should be used as an optimization criterion. \( L \to \max \);

2. Obtaining the most accurate result with respect to the selected objects of diagnostics involving the use of methods that are distinguished by a high reliability of the results that are obtained. As a criterion, the maximum possible accuracy of the results that are obtained as a result of diagnostics should be used, i.e., \( T \to \max \);

3. In terms of restrictions, regardless of the management situation in the HSO, there will always be restrictions on:
   - Resources—financial (money, FR), which the HSO can allocate for diagnostics, information resources that the management has in relation to the diagnosed facilities (IR), and HSO investment to improve the technical condition of the heating networks in the planned period (volume of investments, VI);
   - The reliability of the results of the measures that were taken to diagnose the technical condition of heating networks: the required volume of diagnostics (V), the number of methods that were used (N), and the timing of the diagnostics (T);
   - The risks that are associated with insufficient information for making management decisions on carrying out repair and restoration work (R).

Taking into account the above, in general terms, the model for making an optimal managerial decision on the sustainable development of HSO has the next form, where \( X_i \) is the \( i \)-th managerial decision:

\[
\begin{align*}
L(X_i) & \to \max \\
T(X_i) & \to \max \\
FR_{\min} & \leq FR_i \leq FR_{\max} \\
IR_{\min} & \leq IR_i \leq IR_{\max} \\
VI_{\min} & \leq VI_i \leq VI_{\max} \\
V_{\min} & \leq V_i \leq V_{\max} \\
N_{\min} & \leq N_i \leq N_{\max} \\
T_{\min} & \leq T_i \leq T_{\max} \\
R_{\min} & \leq R_i \leq R_{\max}
\end{align*}
\]  

(1)

Let us comment on the above model, noting the following features of its application:

1. The model can be used either as a single criterion model, and then the corresponding target functions are used when making managerial decisions on diagnostics, or as a two-criteria model with the simultaneous use of two target functions.

2. The minimum and maximum values of the parameters that are included in the restrictions are set by the management of the HSO with the involvement of experts in the relevant field in relation to the conditions of the functioning of a particular HSO at a specific time interval.

3. In the existing economic practice, when making decisions, linear optimization models and the corresponding linear optimization methods, which are proposed to be used at the initial stage are the most common. At the same time, it should be noted that such an approach is significantly simplified: in particular, in addition to the restrictions that take into account the minimum and maximum values of the parameters, there may also be restrictions that connect individual elements of this model and that are, usually, nonlinear in nature. In addition, the target functions that are considered in the framework of this optimization problem, with a more detailed study of the issue are also likely to be nonlinear. All of this leads to the complication of the proposed model and the use of special nonlinear optimization methods. However, it should be noted that such a formulation of the problem requires a significant amount of information, which the majority of HSOs currently do not have.

4. It should be noted that the presented model is rather general. However, it is currently not possible to eliminate this shortcoming for the following reasons. Firstly, the choice of the objective function and the set of restrictions to be taken into account are
largely determined by the features of the functioning of a particular HSO, which does not allow explicitly prescribing the requirements for the model. Secondly, as noted above, a significant obstacle in modeling is the lack of sufficient reliable information to identify the nature of the relationship between the individual factors of the model. In this regard, at the first stages of decision-making by HSO can be reduced to the enumeration of possible diagnostic options, taking into account the priority of the objects to be diagnosed.

4. Discussion

An improvement of the recommended model and decision-making based on it can be ensured on the basis of the creation and implementation of a unified industry digital platform that is used for transmitting technological data in real time and the possibility of using industry technological statistics for scientific purposes. Such preconditions are contained, for example, in the departmental project “Digital energy” [18].

The second issue that is related to decision-making by HSO management in the context of anti-crisis management and requiring discussion in the framework of the study is the improvement of methods for assessing the heating networks structural elements technical state based on diagnostic data. Today, such an assessment is carried out in the HSO mainly on the basis of the available practical experience, which does not allow making objectively substantiated decisions. At the same time, in other industries, approaches that are based on the use of mathematical and information models are quite successfully applied. The interpretation of the monitoring data that characterize the state and operating of technical objects (including heat supply systems) as big data largely determines the methods of their processing, including statistical methods, predictive analytics, machine learning, the use of artificial neural networks etc. The application of these approaches allows for the classification of the state of these objects with a high degree of reliability and the development of a set of measures to prevent the development of defects and the occurrence of emergencies.

Considerable experience in developing models for assessing the state of technical objects which can be recommended and considered in the continuation of the conducted research has been accumulated, for example, in the nuclear industry, where increased requirements for industrial safety are imposed. In particular, among the promising approaches that are used, the methods of identifying trends and forecasting based on time series [19,20], clustering of equipment states in the parameter space using the principal component method [21,22], the use of neural network modeling and machine learning [23], etc. should be noted. Such models can be developed and successfully applied in diagnostics of the state of structural elements of heating networks, which will significantly increase the reliability of heat supply and reduce the cost of repair work and the elimination of emergencies. However, the limiting factors in the development of HSO in this direction are the lack of complete and reliable information for building such models, which was already noted by the authors earlier, as well as the lack of specialists with the necessary competencies in HSO. At the same time, it should be noted that the wider application of digitalization in the heat supply industry will eliminate these obstacles, which will lead to the sustainable development of HSO.

In conclusion, it can be noted that the issues that were identified in the proposed discussion are closely interrelated and should be considered comprehensively as elements of a single organizational and economic mechanism for anti-crisis management in the heat supply industry.

5. Conclusions

New meanings in a changed economic context require transformation both in the economies of countries and at the level of industries and individual organizations within them. The pandemic of 2020–2021, having essentially caused a crisis, forced many business entities, including the heat supply business, to return to the issues of anti-crisis management.
and search for key links in the system of anti-crisis measures. Some researchers clearly point out the need to search for “growth points” in the energy sector [24]. Before the crisis of 2020, scientists very often raised issues of energy saving and the development of various technologies for that [25].

It is obvious that the degree and forms of the pandemic’s impact are quite specific for each of the organizations and are directly dependent on the key characteristics of its products and the markets in which they are sold. For the heat supply industry, the key point in overcoming the crisis is to ensure the proper functioning of engineering systems, which leads to an increasing role of technical diagnostics in the organization of HSO activities. The research that was carried out by the authors made it possible to develop a model for making managerial decisions for the HSO management, which forms the basis of a new methodological approach to the organization of technical state diagnostics which allows ensuring the reliability of heat supply, overcoming the imbalances prevailing in the industry and further sustainable development of HSO. As a further development of the subject that was considered in this study, it seems promising to form new approaches to the processing of diagnostic information using digital technologies.

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