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**Article**

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*Reference:* Glukhova, Miroslava Gennadevna/Zubarev, Aleksandr Andreevich (2017). Economic appraisal of the program of diagnostics of main gas pipelines. In: International Journal of Energy Economics and Policy 7 (2), S. 316 - 326.

International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2017, 7(2), 316-326.

# Economic Appraisal of the Program of Diagnostics of Main Gas Pipelines

**Miroslava Gennadevna Glukhova[1]*, Aleksandr Andreevich Zubarev[2]**

[1]FSBE Institution of Higher Education Industrial University of Tyumen, P.O. Box 625000, Tyumen, Volodarsky's street, 38, Russia,
[2]FSBE Institution of Higher Education Industrial University of Tyumen, P.O. Box 625000, Tyumen, Volodarsky's street, 38, Russia.
*Email: mira_gluhova@mail.ru

**ABSTRACT**

The content of the article is aimed at economically expedient resolution of the problem of industrial and environmental safety of operation of the existing gas pipelines: It provides a brief description of the gas transportation system (GTS) of Russia, highlights the importance of safety and reliability of pipeline transportation for the economic stability of the industry and energy security of the country, demonstrates economic impacts of accidents on the main gas and oil pipelines. It highlights the role of the system of diagnostic maintenance of the linear part of main gas pipelines (LP MGP) in the seamless goods transportation and planning of repair and renewal operations, identifies the drawbacks of the procedures of diagnostic measures used in practice and methods of economic justification of diagnostic works. A method of an economic substantiation of the sequence of the shutdown of objects of MGP in diagnostics is proposed, based on the use of the method of hierarchy analysis in the assessment of the factors of efficiency and cost of diagnostics; the methodological basis for calculating the basic cost parameters of diagnostic studies and the possible damages caused by failure to identify accident-prone areas is presented. An adjustment of the conceptual and logical model to form the program of integrated diagnostics considering the criteria of minimizing the emergency risks and with reduction in the cost of emergency response and restoration operations is proposed. Scheduling the sequence of shutdown of objects of MGP in diagnostics is based on ranking the objects by recommended criteria using a hierarchy method - a pairwise comparison of project elements by their impact on a characteristic which is common for them. This article provides an excerpt from calculation of the program of diagnostic works on LP MGP, forecast of adjustment of the sequence of shutdown of linear parts to repair and change in repair funding. The dynamics of the specific frequencies of emergency stops and costs of their removal at the expense of the adjusted program of diagnostic works is presented.

**Keywords:** Reliability of Pipeline Transportation, Diagnostics, Funding of Diagnostics, Economic Appraisal of Diagnostics Efficiency
**JEL Classifications:** L95, D92, C13

## 1. INTRODUCTION

Russian fuel and energy complex (FEC) plays an important role in the functioning and development of the national economy. On the one hand, this is due to the importance of the FEC in securing the life of society, which on the other hand, it is due to the influence of the FEC on the financial and economic parameters of operation of the national productive forces and the state in general. Russia possesses 45% of the potential world's reserves of natural gas, 13% of oil, 23% of coal and 14% of uranium, i.e., in total, almost 30% of the Planet's natural energy potential. FEC products account for more than a quarter of the total industrial production in the structure of the economy. FEC enterprises secure more than half of all tax payments to the budget system, more than 70% of national budget revenues from exports (Mazur et al., 1990).

Pipeline transport of hydrocarbons plays a significant role in providing energy to all sectors of the national economy. Development of the industry and energy security of the country depends on how efficiently and reliably the oil and GTS operates. The importance of pipeline transport lies in the fact that 100% of the produced gas, 93% of oil and more than 20% of the refined products are moved through pipelines. The length of the Russian main pipelines exceeds 221 thousand km, of which 153 thousand km are main gas pipelines (MGP), 48 thousand km are main oil pipelines, and more than 20 thousand km are main oil-product pipelines. As such, there is a direct relationship between security and reliability of pipeline transportation and economic stability. (Haliev et al., 2005) Besides, the pipeline transport is recognized as the cheapest and the most effective means of delivering oil and gas. The need for transportation of crude hydrocarbons will grow, but the production capacity of the gas pipeline transport might fail to cope with the growing need in transportation. (ANSI/ASME Standard B31.4, 2002) Forecast and dynamics of gas production are presented in Figure 1.

The priority task for gas transportation companies is to ensure reliability and efficiency of the MGP operation by conducting thorough overhaul, technical upgrading, modernization, renovation and new construction. Formation of the restoration programs is associated with the conduct of diagnostic examinations. Stringent conditions of regulation of deadlines and funding volumes of programs of restoration of productive assets of the oil and gas transportation enterprises require increased economic efficiency of repair and renewal operations (RRO) and expanded production volumes (Shilova and Salcheva, 2014). The result of the implementation of restoration projects, due to high capital intensity, depends on the rational use of investment resources, while diagnostics is a necessary information base for efficient planning of restoration works.

Aging of pipeline systems leads to increase in the number of accidents and failures. Dozens of thousands of minor accidents and failures occur each year, which results in losses of millions of cubic meters of gas and causes fires. Growth of energy needs, on the one hand, and aging and deterioration of the equipment, on the other hand, cause an imbalance between supply and demand; pipeline transport is overloaded, while renovation rate is low. Long service life and natural aging of MGP lead to an increased risk of accidents. The accidents often lead to a complete suspension of gas pumping. Direct damage from one accident ranges from 3 to 25 million rubles, depending on the pipeline specifications, while consequential damages can reach 100 million rubles due to reduced gas supply to customers.

Accidents on MGP significantly damage the environment, due to which the enterprise incurs additional costs for the negative impact on the environment. According to information available to Greenpeace, 10-20 million tons of oil and 6-50 billion cubic meters of gas are lost due to leaks and pollute the environment in Russia every year. Leakage of oil and gas results from accidents on main pipelines. Leakage scale ranges from 3% to 7% of the total volume of produced oil or gas.

Accidents result in costs associated with restoration and repair, fines, environmental impacts, which can be difficult to eliminate, as well as loss of the transported product and therefore failure to fulfill contractual obligations, also entailing fines and penalties. The dynamics of costs of environmental protection is presented in Figure 2.

Task of the operating personnel of the gas transportation company is to maintain the entire system of MGP in working order (Budzulyak et al., 2003). The work to ensure reliability and safety of operated gas pipelines and reduce the number of accidents is conducted in the following key areas:

a. Diagnostics of the MGP;
b. Repair and thorough overhaul (replacement of pipes and re-insulation);
c. Reconstruction, modernization and technical re-equipment (Dedeshko and Salukov, 2006).

**Figure 1:** Forecast of gas production by the largest gas producer in the Russian Federation (Report of PJSC Gazprom …, 2016)

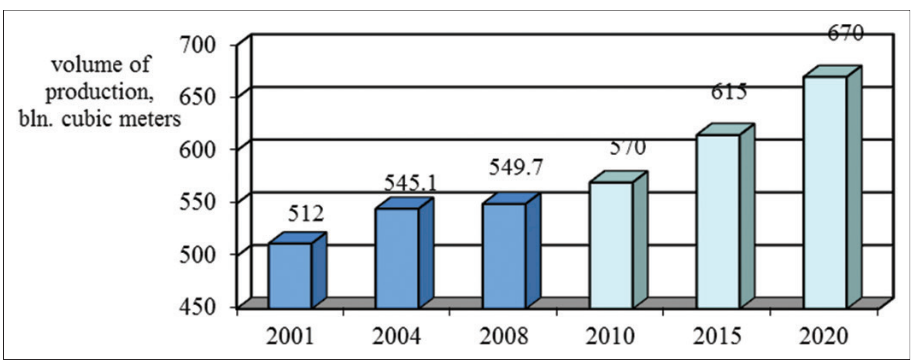
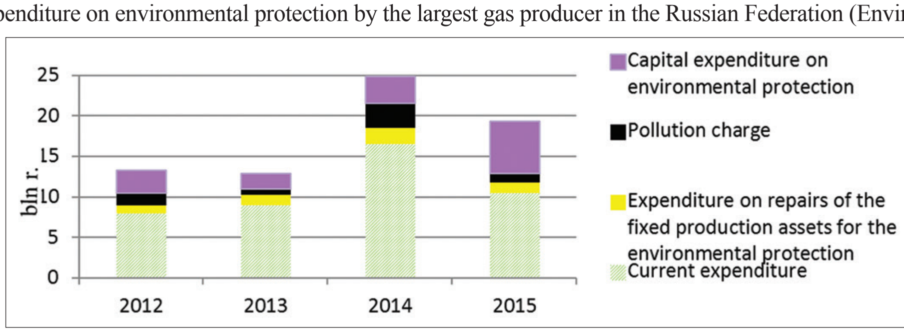



**Figure 2:** Dynamics of expenditure on environmental protection by the largest gas producer in the Russian Federation (Environmental Reports,…, 2016)



Safe operation of pipelines is based on the system of technical diagnostics, which covers most of the gas pipelines and allows to maintain their trouble-free operation thanks to the timely identification and removal of potentially dangerous defects (Harinovskiy, 1998).

Reliability and efficiency of the MGP operation are affected by the following factors:
1. Age structure of gas pipelines;
2. Statistics of failures;
3. Compliance with the rules of technical operation;
4. Timely technical diagnostics;
5. Timely RRO;
6. Quality of design, construction and installation works.

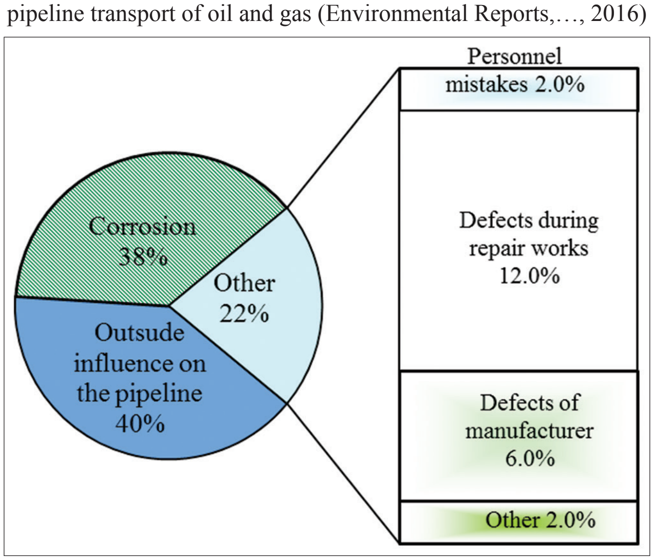
Analysis of the causes of accidents reveals (Figure 3) that most of the accidents could have been prevented by timely conducting of technical diagnostics and elimination of identified defects. The share of such defects sometimes reaches 60%.

Pig inspection (PI) has established itself as the most informative and essentially major method in the diagnostics of the linear part of (LP MGP). (Yakovlev et al., 1992) Despite the inherent drawbacks, PI currently has a number of distinct advantages, compared with other methods of nondestructive inspection of MGP:
a. Relatively high degree of reliability of submitted data;
b. No need to shut down gas pipeline parts and open them to apply nondestructive inspection methods;
c. In most cases, no need to adjust the gas transportation mode directly to the solution of PI tasks.

Results of PI and metric examinations allow to determine the technical condition of each individual part of the pipeline and to develop measures to routinely maintain the operational reliability of the gas pipeline by producing random repair and, if necessary, thorough overhaul of the LP MGP (Albinov et al., 2000).

Diagnostic measures have a direct impact on securing safety of operation of production facilities of MGP. Reliability of operation of production facilities allows to ensure trouble-free goods transportation, which ultimately has a positive impact on the resulting indicators of the enterprise performance (Grib, 2002).

**Figure 3:** Structure of the causes of accidents at the facilities of the pipeline transport of oil and gas (Environmental Reports,…, 2016)




Tasks of reduction of accidents on pipelines and improving industrial and environmental safety of operation of the existing gas pipelines are a priority for the gas transportation enterprise. Modern MGP are operated under conditions of increased requirements to environmental safety, which raises the need to find resources and implement methods that allow to maintain a high level of their reliability at optimum cost for restoration works to ensure trouble-free operation of the gas pipeline transportation. Diagnostics allows not only to plan and determine the volume of RRO, but also to optimize the costs of their implementation (The Formation of the Concept of … "Gazprom.," 1999).

Besides, the diagnostic results serve as a base for planning the RRO. Diagnostics results allow to define this optimal moment, avoiding any additional costs that may be caused by untimely repairs.

A comprehensive system of diagnostics and monitoring of the technical condition of industrial facilities allows to prevent failures, extend the life of gas pipelines, and optimize the allocation of resources during the RRO, which increases the efficiency of gas transportation facilities operation in general (Budzulyak et al., 2003; 1999) The diagnostic maintenance system ensures reliable gas operation due to early detection and analysis of defects, as well as making decisions on necessary maintenance of the equipment.

The system of diagnostic maintenance of the LP MGP solves the following tasks:
a. Technical diagnostics of LP MGP at the optimal time on the basis of defining the priority of examination, factor analysis of operating risk and probability of formation of dangerous defect;
b. Prevention of accidents, failures and incidents in LP MGP;
c. Planning repairs of LP MGP and control over conducting it according to the actual technical condition of the structural elements of LP MGP;
d. Substantiating the decision on the possibility and conditions of further operation of LP MGP elements;
e. Forecasting the technical condition of LP MGP.

The main purpose of the system of diagnostic maintenance of LP MGP is to provide a trouble-free gas transportation in accordance with a target capacity of MGP during its faultless operation and with minimization of costs from natural and man-made risks.

Algorithm of operation planning includes the selection of the structural elements of LP MGP, further consideration of their characteristics, ranking elements by diagnostics priority, selecting the type and method of diagnostics and immediate implementation of the diagnostic works (Budzulyak et al., 2003).

Industrial safety of LP MGP is achieved through technical diagnostics and RRO, while increase in the efficiency of technical and economic indicators of gas transportation is ensured by technical re-equipment and reconstruction of LP MGP, as well as by replacement and restoration of the main and auxiliary equipment, carried out based on the forecast of LP MGP behavior made with the available diagnostic information (Glukhova and Semochkina, 2010).

To date, the existing methods of planning the diagnostic measures are based on determining the optimal technical systems or research models (Vasilevich, 2007). Only a small part of scientific papers is dedicated to the economic rationale for the selection of efficient methods of diagnostics and formation of programs of diagnostic studies (Buktan and Schmidt, 1995; Shiurov and Svetlov, 1998). Review of the scientific papers allowed to reveal the peculiarities of methodological approaches to the assessment and formation of programs of diagnostics of MGP (Budzulyak et al., 1999; STO Gazprom RD 39-1.10-088-2004., 2004).

The following factors are taken into consideration when choosing a kind, type and method of diagnostics:
a. Pipeline category;
b. Pipeline useful life;
c. Pipeline design features;
d. Availability of violations of security areas of pipeline run;
e. Availability of LP MGP structural elements described as potentially dangerous and extremely important and difficult to diagnose.

Scientifically and methodically reasoned opinion about the technical condition of LP MGP is based on the analysis of:
a. Data from all conducted examinations;
b. Design and operational documentation;
c. Results of the conducted tests and retests;
d. Results of calculations to determine the strength, residual resource and analysis of operation risk.

The methodological approaches to the formation of diagnostic measures are generally based only on the technical characteristics, while it is often recommended to rank parts for diagnostics using the expert-scoring method (Budzulyak et al., 2003). In this case, the key indicator in the selection of diagnostics methods is the cost of such research. Since the priority of shutdown to diagnostics is expertly determined on the basis of the calculation of points, two major drawbacks arise: Selection of sequence of the object shutdown at the similar condition and underestimation of other factors that have a direct impact on the efficiency of the enterprise operation.

As practice shows, technical diagnostics in the process of the facility operation is performed in order to check its efficiency, detect defects, changes in operating practices and technical condition of LP MGP, as well as the conditions of interaction with the environment. However, in addition to diagnostic examinations with the use of technical means, there is a need to predict its residual resource, assess unsafety (risk) of further operation, as well as conclusions on the need of repair or reconstruction, definition of time, type and volume of repair works, and the development of proposals about changes in operating practices (Chernyev and Belkin, 1999).

The main shortcomings of the existing methods of economic justification of diagnostic works in LP MGP result in the increased costs of their holding, reduction in feasibility of repairs and, as a consequence, drop in the cost efficiency of the program of diagnostics.

## 2. METHOD

The authors recommend using the method of the hierarchy analysis as a methodological basis of ranking factors that affect the cost efficiency of a program of diagnostic works (Saati, 1993). In the first place, it is recommended to identify factors that influence the cost of diagnostics in order to determine the costs of diagnostics of the objects of the main pipeline transport. The following grouping of factors is proposed: Climatic conditions, technical parameters of the pipeline, characteristics of the pumped product, producing characteristics of the pipeline (Table 1).

Secondly, it is proposed to rank factors that influence the cost of diagnostics using the method of hierarchies. The method of hierarchies will allow to structure the problem of choice as a hierarchy of technical and economic indicators of projects, with detailed parameters of their implementation. The criteria for comparison are ranked in a similar manner. Method of hierarchies assumes a pairwise comparison of project elements by their

**Table 1: Arrangement of factors that influence the efficiency of diagnostics**

| Group of factors | Individual factors |
|---|---|
| Climatic conditions | Soil characteristics |
| | Ambient temperature |
| Characteristics of the pumped product | Product type |
| | Operating temperature (minimal, maximal and normal) |
| | Impurity content |
| Technical parameters of the pipeline | Diameter |
| | Length |
| | Nominal pipe wall thickness |
| | Pipe wall thickness that differs from the nominal (approximate length and position) |
| | Welded and seamless pipes |
| | Properties of the pipe metal |
| | Bends |
| | Data on past repairs |
| Producing characteristics of the pipeline | Pipeline age |
| | Pressure |
| | Load |
| | Outline map of the pipeline |
| | Data on the ongoing examinations |
| | Expected level of corrosion (interior and exterior) |
| | Type of the inner/outer coating |
| Timely implementation of the repair and renewal operation on the objects | Duration of repair works |

impact on a characteristic which is common for them. Thus, the application of the method of hierarchies will allow to build priority for the shutdown of objects for repairs not only by the technical condition of the object, but also by the range of important criteria. Ranking should be made given the restrictions of resources for diagnostics, RRO, which will allow to increase feasibility of spending funds on their implementation (Table 2).

It is proposed to justify the costs of diagnostics with limited resources (Kiselitsa, 2006) by calculating the costs through specific indicators, given the restrictions on the use of available resources (f1):

$$\begin{cases} \sum \text{Diag} = \text{Cs.d.*Ld+Cs.r.*Lr+Cl*Nl} \\ \sum \text{Diag} £ \sum \text{RRO+D} \end{cases} \quad (1)$$

Where ΣDiag is amount of costs of diagnostics including costs of defects elimination, million rubles;
Cs.d.is specific cost of diagnostics, million rubles/km.;
Ld is length of the pipeline part to diagnose;
Cs.r. is specific cost of recovery of the pipeline part, million rubles/km.;
Lr is length of the recovered pipeline part, km.;
Cl is cost of repairing a local defect, million rubles/pcs.;
Nl is number of local defects;
ΣPRO is estimated cost of RRO;
D is expected damage in case of accident, including penalties.

Functional dependency of the specific cost of diagnostics per 1 km of the pipeline on the RRO resource-intensity factors is as follows (f2):

$$\text{Cs.d.} = \begin{cases} f(A_1, A_2, ..., A_n) \le A \\ f(B_1, B_2, ..., B_n) \le B \\ f(C_1, C_2, ..., C_n) \le C \\ f(D_1, D_2, ..., D_n) \le D \end{cases} \quad (2)$$

Where,
Cs.d. is specific cost of diagnostics;
A,B,C,D is total resource-intensity of RRO.

In practice, the damage caused by accidents on the main transport is assessed in three areas (STO Gazprom 2-2.3-095-2007., 2007):

1. Damage caused by the damage of the linear part of the pipeline;
2. Damage caused by the leakage of hydrocarbon;
3. Damage caused by environmental pollution.

It is suggested to use a more complete set of criteria by which the damage is calculated. Thus, the expected damage from accidents on main pipelines can be determined as follows (f3):

$$D = \Sigma P_j D_j - \Sigma S_j \quad (3)$$

Where, $P_j$ is a likelihood of emergence of factors that determine the parameters of the expected damage during the pipeline operation, considering zoning of the territory and classification of pipeline by risk indicators (Kiselitsa and Shilova, 2016);
$D_1$ is damage caused by damage to structures, equipment and communications, and their restoration; compensation to victims of accidents;
$D_2$ is damage caused by loss of the transported products;
$D_3$ is damage caused by idle time in accordance with contractual relationships with the companies supplying and consuming hydrocarbons;
$D_4$ is damage caused by technological impacts on the environment;
$D_5$ is damage associated with payment of penalties for violation of legal and regulatory requirements;
$S_j$ is insurance compensations, compensations under the contract agreements.

Assessment of damage caused by damage to structures, equipment and communications, and their restoration; compensation to victims of accidents (f4):

$$D_1 = \sum_{i=1}^{n} C_i P_i + \sum_{i=1}^{n} Z_i P_i + \sum_{i=1}^{n} K_i P_i \quad (4)$$

Where $C_i$ is the cost of damaged and destroyed structures, equipment, communications and other facilities;
$Z_i$ is cost of their restoration;
$R_i$ is costs including insurance payments and compensation to victims of accidents;
$P_i$ is indicators of the likelihood of accidents;
n is a number of objects under study or their individual elements.

Assessment of damage caused by loss of the transported products (f5):

$$D_2 = \sum_{i=1}^{m} V_i C_i t_i P_i \quad (5)$$

Where,
m is a number of similar objects;
$V_i$ is a volume of product lost in the unit of time;
$C_i$ is a cost of the unit of the product volume;

**Table 2: Ranking factors using the method of hierarchies**

| Factors | Resources | | | |
|---|---|---|---|---|
| | Labor | Timing | Production (assets) | Material |
| Climatic conditions | A1 | B1 | C1 | D1 |
| Characteristics of the pumped product | A2 | B2 | C2 | D2 |
| Technical parameters of the pipeline | A3 | B3 | C3 | D3 |
| Producing characteristics of the pipeline | … | … | … | … |
| Timely implementation of the repair and renewal operation on the objects | An | Bn | Cn | Dn |
| Total resources for RRO | A | B | C | D |

RRO: Repair and renewal operations

$t_i$ is duration of the product leakage from a damaged or destroyed object;
$P_i$ is a likelihood of the predicted phenomena.

Assessment of damage caused by idle time in accordance with contractual relationships with the companies supplying and consuming hydrocarbons (f6):

$$D_3=\sum_1^f H_f P_f \qquad (6)$$

Where,
$H_i$ is a volume of gas not delivered on time;
$P_i$ is a likelihood of damage caused by idle time.

Assessment of damage caused by technological impacts on the environment (f7):

$$D_4=\sum_1^y F_y C_{y1} P_{y1}+\sum_1^y V_y C_{y2} P_{y2}+\sum_1^y G_y C_{y3} P_{y3}+\sum_1^y N_y C_{y4} P_{y4} \qquad (7)$$

Where $F_y$, $V_y$, $G_y$, $N_y$ are respectively a land area, volume of air, surface of water, number of objects of flora and fauna, contaminated or affected by accidents;
$C_{i1}$-$C_{i4}$ is valuation of the unit of measurement of polluted environment;
$P_{i1}$-$P_{i4}$ is a likelihood of pollution resulting from an accident.

Assessment of damage associated with payment of penalties for violation of legal and regulatory requirements (f8):

$$D_5=\sum_1^a U_{ay} P_a+\sum_1^b U_b P_{b1} P_{b2}+\sum_1^c U_c P_{c1} P_{c2} \qquad (8)$$

Where, $U_a$, $U_b$, $U_c$ is an appropriate size of potential penalties automatically withdrawn on unconditional basis, on administrative basis, on judicial basis;
$P_a$, $P_{b1}$, $P_{c1}$ is a likelihood of violations of the requirements of legal and regulatory framework;
$P_{b2}$, $P_{c2}$ a likelihood of liability for violation of the legal and regulatory framework.

Increment in profit (IP) from the diagnostics is formed due to the following factors (f9):
1. Cost savings through reducing the volume of repairs by random repair.
2. Elimination of accidental losses due to dangerous defects, which could not be detected by conventional methods.
3. Cost savings in testing.

$$IP = \Delta PR + D - \Delta PD \qquad (9)$$

At the same time, the cost of the product transportation is increased due to the cost of diagnostics.

Increase in profits through reducing costs of repairs DPR is calculated as follows:

$$\Delta PR = \Delta CR_1+\Delta CR_2+\Delta CR_3+\Delta CR_n \qquad (10)$$

Where,
$\Delta CR_1$ is a reduced cost of repairs with the pipe replacement (if the length of an individual part exceeds the length of a standard pipe) (f11);
$\Delta CR_2$ is a reduced cost of pipeline repair with a continuous replacement of the coating in the trench without the pipe replacement (f12);
$\Delta CR_3$ is cost of repairs to eliminate local defects, including defects that require pipe cutting and pipe coil welding (up to one pipe) (f13);
$\Delta CR_n$ is reduced cost of preparatory and final repair works (14):

$$\Delta CR_1 = \Delta L_1\text{-}CP_1 \qquad (11)$$

Where,
$\Delta L_1$ is reduction in the length of the repair part, km;
$CP_1$ is cost of repair of 1 km of pipe.

$$\Delta CR_2 = \Delta L_2\text{-}CP_2 \qquad (12)$$

Where,
$\Delta L_2$ is reduction in the length of the repair part, km;
$CP_2$ is cost of repair of 1 km of coating.

$$\Delta CR_3 = n \cdot CP_3 \qquad (13)$$

Where,
n is number of defects;
$CP_3$ is cost of repair of one defect.

$$\Delta CR_n = \Delta L_1 \cdot CP_n \qquad (14)$$

Where,
$CP_n$ is cost of preparatory and final repair works per 1 km of pipe.

Current costs of diagnostics in year t ($\Delta CD$) include:
1. Payment for services of the Center for Technical Diagnostics - DCCTD;
2. Current costs of preparatory and final works (passing pigs, stockpiling products with the consumer or the free space with the suppliers) – $\Delta CPFW$:

$$\Delta CD = \Delta CCTD + \Delta CPFW \qquad (15)$$

The proposed adjustment of methodological tools of economic appraisal of diagnostics will allow to:
1. Justify the required amount of expenses for diagnostics in terms of limited financial resources.
2. Optimize the time and volume of the emergency response and restoration operations.
3. Increase the efficiency of utilization of production and economic resources of the enterprise.
4. Extend the operation life of MGP.
5. Ensure the reliability of gas supply to consumers.

The proposed approach can also be applied to define the efficiency of other methods of control over the technical condition of industrial equipment of the potentially hazardous industrial facilities. The

authors propose a set of criteria for determining the priority of shutdown of the object for the diagnostic service as an improvement of approach to the planning of diagnostic measures. In the formation of the program, the technical condition of the object is taken into account in the first place, while the arrangement of works is aimed at maintaining the MGP objects in the state of reliability and fail-safety, preventing accidents, reducing costs of repair and improving the quality of repair (Arbuzov et al., 2010). It is proposed to use the following criteria to establish a sequence of shutdown for the diagnostics of the objects included in the program:
1. Climatic conditions of diagnostics implementation.
2. Total damage caused by accidents.
3. Technical and operational parameters of pipelines.
4. Technical condition of the object (reliability, operational safety).
5. Required capacity (strategic parts).
6. Total costs of the object diagnostics, proprietary funds of branches for diagnostics.

In order to schedule the sequence of shutdown of objects of MGP in diagnostics according to the program, it is suggested to rank the items by recommended criteria using a hierarchy method: A pairwise comparison of project elements by their impact on a characteristic which is common for them. As such, these methodological tools will help to build a priority to shut down the objects for repair not only by the technical condition of the object, but by a range of important criteria.

The model of ranking the LP MGP objects using the hierarchy method, based on pairwise comparison of alternatives (Ai) by criteria (Ei) and the calculation of global priority (W) - the sum of the products of obtained values on the criterion on weighting this criterion – is presented in Table 3.

The conceptual and logical model of formation of the diagnostic program was adjusted by the authors based on the criterion of ranking objects (Figure 4).

The adjusted model of planning the diagnostics program will allow to not only take into account the technical condition of the object when planning, but also to use the economic parameters of the program implementation. This approach will allow to find the optimal solution for determining the prioritization of diagnostics examination, taking into account all the conditions for the implementation of works.

Assessment of damage in case of an accident due to the defect development and prediction of the objects condition should also have impact on the selection of objects for diagnostic examinations.

The author's approach will allow to improve the efficiency of recovery operations, reduce costs of elimination of the impact of accidents and payment of fines, increase the reliability of the GTS functioning, and thereby increase efficiency of the gas transportation enterprise operation.

## 3. RESULTS

The key planning parameters of the programs of diagnostics of the LP MGP include the amount of diagnostic activities, duration, time of implementation, as well as the need for resources (material, fixed production assets and labor resources). The selection of objects for inclusion in the schedule of diagnostics is planned in accordance with the residual resource of MGP, as well as the overall score of the condition of LP MGP. The scope of work is defined on the basis of the choice of method and type of diagnostics, as well as the work structure. The amount of diagnostic work affects the duration of their performance, and therefore, the period of their implementation. The duration of diagnostics takes into account the length of the main and ancillary works, as well as scheduled breaks. Resource capacity is planned on the basis of regulatory documents (consumption standards, standards of labor intensity, standards of the headcount for certain types of work, etc.). The diagnostics program included 8 parts, priority and the expertly obtained score. The priorities of shutdown for repair were calculated using the method of the hierarchy analysis by the proposed criteria in order to adjust the diagnostics program. The matrices of pairwise comparisons were built in order to determine the importance of the criteria, which allowed to reflect the weight of each parameter for the importance of the diagnostics priority. The result of definition of the criteria weights showed that the technical condition of the object and the climatic conditions had the greatest weights. The criteria of technical and operational parameters and costs of diagnostics had the smallest weights. The calculated weights of the criteria will be used to rank the objects by the priority in shutdown for repair.

This approach ensures taking into account all the parameters of the program implementation, including economic aspects, which

**Table 3: Ranking the objects of diagnostics using the hierarchy method**

| Criteria (Ej) | Objects (Ai) | | | |
|---|---|---|---|---|
| | Object 1 | Object 2 | Object … | Object m |
| Climatic conditions of diagnostics implementation | $W_{E1}^{A1} * W_{E1}$ | $W_{E1}^{A2} * W_{E1}$ | … | $W_{E1}^{Am} * W_{E1}$ |
| Total damage caused by accidents | $W_{E2}^{A1} * W_{E2}$ | $W_{E2}^{A2} * W_{E2}$ | … | $W_{E2}^{Am} * W_{E2}$ |
| Technical and operational parameters of pipelines | … | … | … | … |
| Technical condition of the object (reliability, operational safety) | … | … | … | … |
| Required capacity (strategic parts) | … | … | … | … |
| Total costs of the object diagnostics, proprietary funds of branches for diagnostics | $W_{E6}^{A1} * W_{E6}$ | $W_{E6}^{A2} * W_{E6}$ | … | $W_{E6}^{Am} * W_{E6}$ |
| Global priority | $\sum W_{Ei}^{A1} * W_{Ei}$ | $\sum W_{Ei}^{A2} * W_{Ei}$ | … | $\sum W_{Ei}^{Am} * W_{Ei}$ |

**Figure 4:** Conceptual and logic model of formation of the program of complex diagnostics of linear part of main gas pipelines

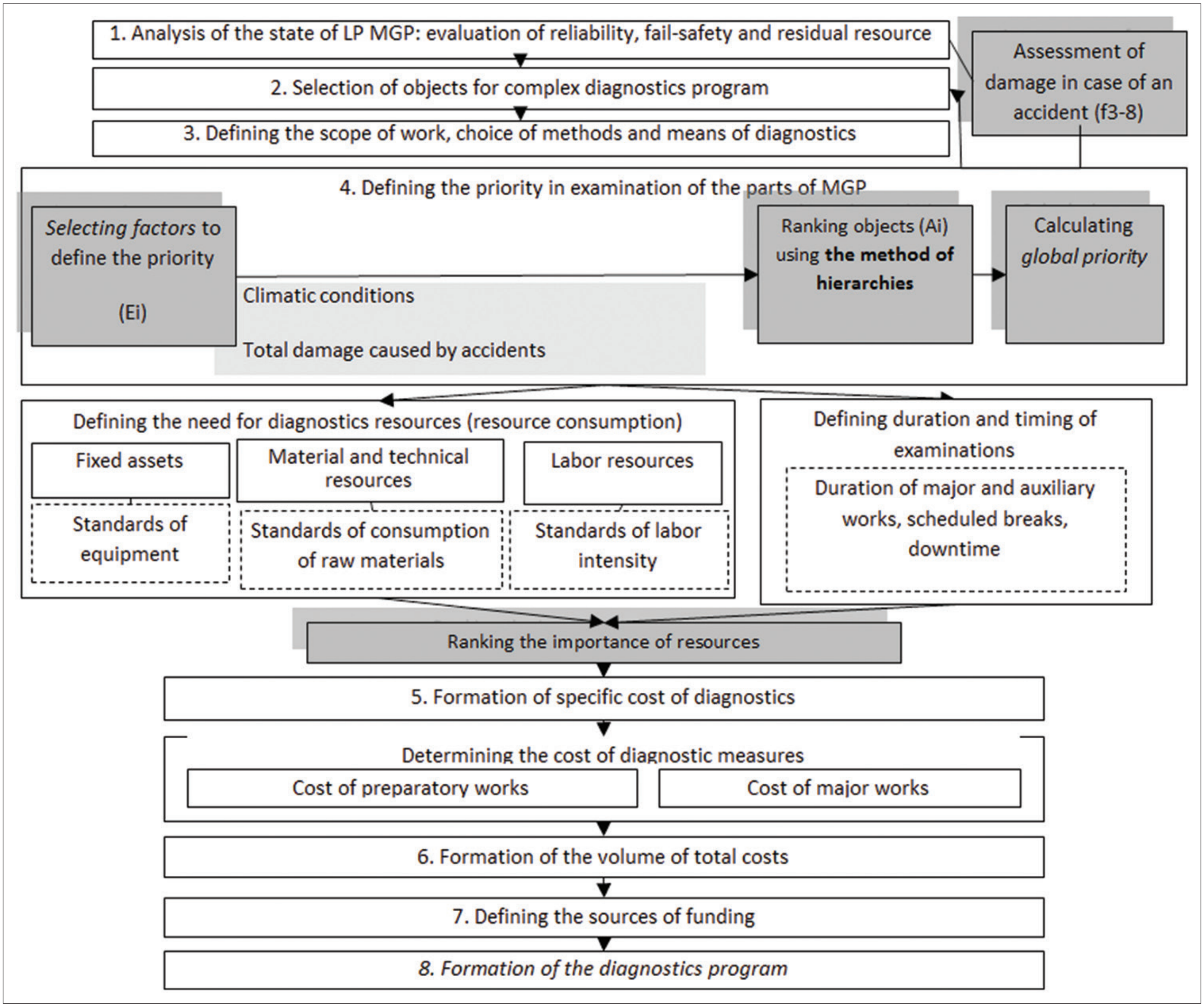



**Table 4: Comparison of alternatives given the weight of the quality criteria**

| The quality criteria | $A_1$ | $A_2$ | $A_3$ | $A_4$ | $A_5$ | $A_6$ | $A_7$ | $A_8$ |
|---|---|---|---|---|---|---|---|---|
| Climatic conditions of diagnostics implementation | | | | | | | | |
| Sum | 10.60 | 15.40 | 34.67 | 18.98 | 27.20 | 10.48 | 12.18 | 18.53 |
| Given the weight | 1.95 | 2.83 | 6.38 | 3.49 | 5.01 | 1.93 | 2.24 | 3.41 |
| Total damage caused by accidents | | | | | | | | |
| Sum | 12.98 | 21.34 | 10.39 | 7.79 | 44.00 | 2.93 | 17.53 | 17.14 |
| Given the weight | 1.62 | 2.67 | 1.30 | 0.98 | 5.51 | 0.37 | 2.19 | 2.15 |
| Technical and operational parameters of pipelines | | | | | | | | |
| Sum | 10.98 | 15.20 | 28.00 | 15.87 | 32.00 | 7.06 | 10.12 | 6.32 |
| Given the weight | 0.79 | 1.09 | 2.01 | 1.14 | 2.30 | 0.51 | 0.73 | 0.45 |
| Technical condition of the object | | | | | | | | |
| Sum | 34.00 | 18.25 | 12.93 | 7.93 | 30.83 | 4.46 | 15.78 | 8.33 |
| Given the weight | 14.80 | 7.95 | 5.63 | 3.45 | 13.42 | 1.94 | 6.87 | 3.63 |
| Required capacity | | | | | | | | |
| Sum | 15.20 | 27.14 | 17.68 | 22.14 | 7.73 | 6.45 | 30.00 | 12.14 |
| Given the weight | 1.75 | 3.12 | 2.03 | 2.54 | 0.89 | 0.74 | 3.45 | 1.39 |
| Total costs of the object diagnostics | | | | | | | | |
| Sum | 9.93 | 28.50 | 12.25 | 17.40 | 11.17 | 18.93 | 18.44 | 7.03 |
| Given the weight | 0.68 | 1.96 | 0.84 | 1.20 | 0.77 | 1.30 | 1.27 | 0.48 |
| Sum of alternatives | 21.59 | 19.62 | 18.19 | 12.80 | 27.89 | 6.79 | 16.75 | 11.52 |

allows to justify the funds spending on its implementation. Table 4 provides the comparison of alternatives with regard to the criteria given their significance.

Definition of the sum of alternatives is a global priority to select the sequence of the comprehensive diagnostics examination. According to the calculations, objects No. 5 and 1 have the highest priority, and No. 6 has the lowest priority. The sequence of works on the LP MGP can be changed on the basis of the recommendations of the authors about adjustment of the MGP diagnostics program (Table 5).

Need in funding of the diagnostics program is presented in Table 6.

Planning of the diagnostics program will allow to ensure the reliability of GTS, on the one hand, and to optimize the costs of the program implementation, on the other hand (Glukhova, 2008). The proposed recommendations for adjustments of the program of MGP diagnostics are aimed primarily at maintaining the technical condition of the existing GTS, and in the future – on the development of operational safety and reliability of LP MGP based on the results of diagnostics. The sooner an object is diagnosed, the sooner the most dangerous defects that can lead to serious accidents can be eliminated, which will ultimately affect the efficiency of functioning of the enterprise and GTS in general.

The diagnostics program is aimed at improving the state of the fixed assets of MGP, development of operational reliability and increase in performance of GTS, as well as prevention of disruptions in gas supplies. The results of LP MGP diagnostics will allow to optimize planning and preventive works. The accident rate will decline due to the timely implementation of RRO, and hence the additional unplanned costs for the elimination of the consequences of accidents (Figure 5).

**Table 5: Adjustment of the program of implementation of diagnostics examination**

| Object | Priority of shutdown for repair | | Time of implementation | |
|---|---|---|---|---|
| | Target | Proposed | Target | Proposed |
| 1 | 4 | 2 | Q III | Q II |
| 2 | 2 | 3 | Q I | Q I |
| 3 | 5 | 4 | Q II | Q II |
| 4 | 6 | 6 | Q IV | Q III |
| 5 | 1 | 1 | Q I | Q I |
| 6 | 7 | 8 | Q III | Q IV |
| 7 | 3 | 5 | Q II | Q III |
| 8 | 8 | 7 | Q IV | Q IV |

Forecast of emergency shutdowns and the costs of their elimination are shown in Figure 6, which allows to make a conclusion about the extension of the pipeline operation as a result of the timely repair works.

In general, the proposed methodological approach will allow enterprises to achieve overall reduction in the number of accidents and costs of their elimination, which will ensure high efficiency of oil and gas pipelines operation and the reliability of their operation.

## 4. DISCUSSION

The methodological approach to the economic justification of the volumes and types of diagnostic activities, proposed by the authors in the article, can also be applied in related and other industries. For example, recommendations on systematization of risk factors and their ranking can be used at enterprises engaged in the transportation of oil and oil products through main pipelines. The article presents the use of the method of hierarchy analysis both for evaluating the significance of various risk factors and for determination of the most optimal methods of diagnostics at the production facilities of MGP. Due to the universality of the presented methodology of ranking various indicators, the use of this technology of planning the program of diagnostics examinations can also be applied to railway companies. Conceptual and logical model of the formation of the program of comprehensive diagnostics is of interest for the majority of industrial enterprises. Repairs of production facilities often raise the problem of choosing the most optimal solutions: Maintenance repair, modernization of equipment, purchase of new fixed assets. Each of these solutions contains a variety of options for their implementation, which defines multivariate appraisal of their economic efficiency. The model of formation of the program of comprehensive diagnostics of production facilities of industrial enterprises, including a system of factors to determine the priority, allows to solve the problem of choosing the best option in terms of various scenarios of recovery of the enterprise capacities.

## 5. CONCLUSION

The current accident rate leads to the growth of excessive additional costs of elimination of consequences of accidents, which adversely affects the enterprise performance. Analysis of causes of accidents reveals that most accidents can be prevented through timely diagnostics. Safe pipeline operation relies on the system of diagnostics, which allows to maintain its trouble-free operation thanks to the timely identification and elimination of potentially dangerous defects. Diagnostic results allow to define

**Table 6: Need in funding of the LP MGP diagnostics program**

| Indicator | Amount, thousand rubles | | Structure, % | |
|---|---|---|---|---|
| | Target | Adjusted | Target | Adjusted |
| Total costs, of which: | 102723 | 99640.83 | 100 | 100 |
| By a contractor | 85259.68 | 82701.88 | 83 | 83 |
| In-house | 17462.83 | 16938.94 | 17 | 17 |
| Sources of funding, of which: | 102722.5 | 99640.83 | 100 | 100 |
| Proprietary funds | 65742.4 | 62660.73 | 64 | 63 |
| Investment resources of the parent company (founders) | 36980.1 | 36980.1 | 36 | 37 |

LP MGP: Linear part of main gas pipelines

**Figure 5:** Trend analysis of the specific accident rate on MGP (Malyushin and Minmyalo, 2010; Environmental Reports,…, 2016)

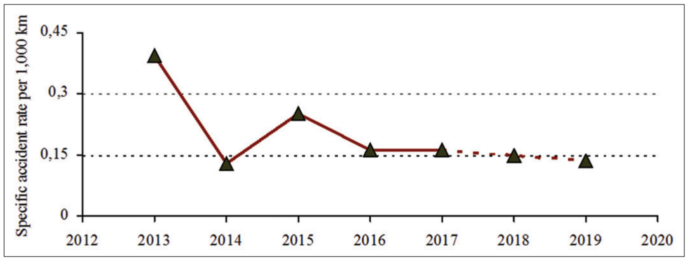
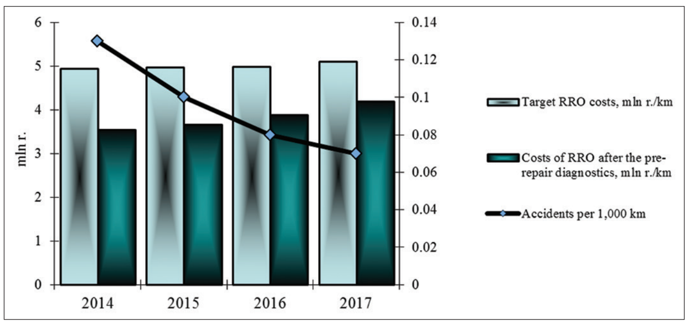



**Figure 6:** Forecast of emergency shutdowns and the costs of their elimination based on diagnostics results (Environmental Reports,…, 2016)




the technical condition of each individual part of the gas pipeline and to develop measures to maintain the operational reliability of the gas pipeline.

The authors proposed to determine the sequence of shutdown of objects for diagnostics using the method of hierarchies as an improvement of the economic tools of economic assessment and planning of the program of diagnostic works. In this regard, they propose to identify a number of criteria, which include the most important technical and economic parameters of the project. Implementation of planning using the method of hierarchies will have an impact on the variation of the main planned figures of the program of diagnostics of the LP MGP. The authors identified the key areas of adjustment of the program of diagnostics of the MGP, including organizational and economic measures aimed at optimization of program of the MGP examination. The recommended methodological approach to the planning of diagnostics activities lies in formation of the criterion tools for prioritizing the shutdown of objects for diagnostics, taking into account technical and economic conditions of the program, as well as limited resources for diagnostics.

Planning of diagnostics activities includes key planned figures: Amount of diagnostics activities, duration, time of implementation and need for resources. It was suggested to select objects for inclusion in the schedule of diagnostics in accordance with the residual resource of MGP, as well as the sum of the scoring assessment of the condition of the LP MGP. Improving the efficiency of diagnostics planning will be achieved through adjusting the sequence of diagnostics of the objects of the LP MGP. The adjustment is carried out taking into account the climatic conditions of the project implementation, the predicted value of the damage caused by accidents, technical condition of the object, required capacity of the pipeline, as well as the total cost of diagnostics. Assessment and analysis of the risk of each part of the MGP allow to identify priority of shutdown of these parts for diagnostics and to adjust the time of implementation of examinations. Thus, the improvement of the system of diagnostics activities will allow to minimize the risk of an emergency and the negative consequences of possible accidents.

Implementation of the program of diagnostics will allow to increase the reliability of operation of the production facilities of MGP, which will allow to increase the production capacity of the GTS. Since the diagnostics results serve as the basis for planning the RRO, the high-quality planning of diagnostics activities will ensure proactive pace of repairs over the pace of growth in the number of dangerous defects, decline in the cost of elimination of accidents and payment of fines for polluting the environment, and the reliability of gas supply to consumers. Decline in the specific frequency of accidents is projected in the planning period. The life of MGP operation is projected to extend by an average of 8 years. Decline in the costs of emergency repair works at MGP in the planning period will reduce the cost of gas transportation and increase the profitability indicators, and hence improve the efficiency of gas transportation enterprise operation.

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