Since 2009, Gazprom JSC has been improving management in the part of technical condition and integrity of gas-transportation system (GTS) control on the basis of regulatory documents [1, 2], which have defined the following innovative target parameters of the mentioned system:

- centralization of decision-making process at developing diagnostics, maintenance, and repair programs;
- transition from «cost management» (economic approach) to «indicators management» (technical-and-economic approach);
- using the indicators of reliability and industrial risk of the trunk gas pipelines linear parts (TGP LP) operation as the basic ones.

New methodical approaches declared in documents [1, 2] are realized in Gazprom recommendations R 2-2.3-691-2013 'Methodological guidelines – Formation of technical diagnostics and repair programs for gas pipelines in Gazprom JSC Unified Gas-Supply System' (further – Methodological guidelines) [3], developed in the scope of standard normative documentation for the System of TGP LP Diagnostics and Integrity Management. These Methodological guidelines are the analytical annex to Regulations [4] specifying functions and roles of participants as well as terms and milestones of long-term planning periods (5 years and more) of TGP LP diagnostics, maintenance, and repair activities. Analytical procedures standardized in Methodological guidelines are based on provisions and terminology concerning reliability and industrial risk as it’s specified in the Russian Federation and the Gazprom JSC standards [3–8].

Methodological guidelines have been developed with objective of forming a comprehensive approach to development of technical diagnostics and repair programs for operated linear parts of GTS facilities providing the required level of reliability and safety and taking into account the whole scope of technical, financial, economic, and organizational restrictions. It is based on the single management decision-making model for long-term planning of diagnostics, maintenance, and repair in the framework of cost limits for GTSs in general. The estimates of reliability and industrial risk indicators calculated on the basis of a general representative set of TGP LP facilities («inter-valve sites») of 19 affiliated gas-transportation companies (GTC) operating about 160000 km of gas mains in the scope of Gazprom JSC have been used for the initial data of the model. The cost limit is planned for each current year and serves as an external limiting factor for the scope of TGP LP facilities being optimized. Internal restrictions are represented by requirements to reliability and risk parameters, according to which decisions on diagnostics, maintenance, and repair scenarios are made by the affiliated GTCs.
Methodological guidelines [3] are based on the two-level (GTC and Gazprom JSC levels) control of GTS in relation to its technical condition and integrity.

The GTC level pursues the following primary aims:

- estimation of technical condition and reliability indicators for TGP LP operation, including a quantitative assessment of safe operation terms and expected frequencies of critical failures;
- estimation of expected damages and industrial risk indicators at occurrence of critical failures at TGP LP sections;
- ranging of TGP LP sections within GTC responsibilities by criteria of reliability and safety;
- checking of TGP LP sections workability criteria taking into account restrictions implied by reliability and safety indicators in order to make proper decisions about necessity, deadlines and optimal scopes of technical diagnosing, maintenance, and/or repair works;
- choosing and carrying out of TGP LP sections diagnostic, maintenance, and repair activities, provided that control and/or maintainability criteria are tested and met as well as planned periods for diagnostics and repair/maintenance works on the basis of GTS load balance schemes within GTC are approved;
- assessing of expected costs for carrying out of TGP LP sections technical diagnostics and/or repairs within GTC, and total expected costs for GTC;
- compiling scenarios of TGP LP technical diagnostics and/or repairs within GTC on the basis of less costly solutions meeting the requirements of TGP LP sections control and maintainability, reliability and safety, coordinated for a long-term period with the General Scheme of the Uniform Gas-Supply System (UGSS) development within GTC;
- forming of GTC offers (applications) to programs of the Gas Mains Diagnostics and Integrity Management System;
- forming of GTC offers (applications) to programs of the GTS Diagnostics and Integrity Management System all over the GTS on condition of meeting Gazprom JSC cost limit criteria in the part of technical diagnostics and repairs;
- defining of requirements for updating consolidated timesheets of GTCs offers (applications) to programs of the GTS Diagnostics and Integrity Management System at default to fulfill cost limits criteria;
- forming of long-term programs for GTS TGP LP technical diagnostics and repairs within a specified period.

General algorithm of estimated substantiation and formulation of offers for long-term GTS technical diagnostics and repair programs is given on fig. 1.

General mathematical task includes the following:

- general scope (multitude) of facilities (objects) \( O_{GTS} = \{ O_1, \ldots, O_M \} \) is represented by TGP LP ‘inter-valve sites’ operated by different GTCs;
- facilities \( O \) are characterized at certain time \( t \) by a number of (time-dependent) indicators: permissible working pressure \( p \); indicators of technical condition \( K_{TC} \), reliability \( S \) and industrial risk \( R \), i.e. \( O_j = O_j (t, p, K_{TC}, S, R) \); the initial state of the system (at the time of carrying out estimation analysis) is characterized by a set of similar indicators with index 0, i.e. \( O_0 = O_0 (t_0, p_0, K_{TC0}, S_0, R_0) \); these indicators are partly interdependent (risk and reliability, pressure and reliability, etc.);
- all above indicators tend to become ‘worse’ with operation time (as reliability and permissible working pressure decrease, and industrial risk grows); to compensate deterioration of the system that can lead to unacceptable consequences (fault/failure resulting in gas shortfalls due to idle time for repair; expenses for emergency restoration; direct damage to business and environment...

\[ O_j = O_j (t, p, K_{TC}, S, R) \]

\[ O_0 = O_0 (t_0, p_0, K_{TC0}, S_0, R_0) \]
including population and personnel) it is necessary
to carry out management activities \( (E^a_{ij}(t_j)) \) at
facilities \( (O_i) \) at relevant periods of time \( (t_j) \) to
bring the system in condition meeting accepted
requirements of integrity (workability and safety).
Requirements to estimated TGS LP integrity are
considered fulfilled, if the following criteria are
satisfied simultaneously:
\[
p_{\text{calc}}(t) \geq [p]; Q_{\text{calc}}(t) < [Q]; S_{\text{calc}}(t) < [S];
D_{\text{calc}}(t) < [D]; \lambda_{\text{calc}}(t) < [\lambda],
\]
where indexes \( i \) and \( j \) are omitted, and index ‘calc’
means that indicators in left parts of inequalities
are calculated for time \( t \geq t_{ij} \); main indicators [3]
are the permissible working pressure \( (p) \), fault
probability \( (Q) \), cumulative industrial risk \( (S) \),
cumulative damage \( (D) \), specific frequency of
failures \( (\lambda) \) (of the last three indicators it is enough
to choose two); indicators in square brackets in
right parts of inequalities define the appointed
permissible (acceptable) values;
\[\text{• management activity is physically}
\]
characterized by volumes of repair works
(potential alternatives are pressure decrease
and reconstruction), which significantly differ
depending upon their type: selective repair (SR)
of only critical pipe sections on site \( O_f \), or capital
repairs (CR) of the whole pipeline length. Essential
difference between these two main scenarios is in
the following:
- in the first case, total SR costs are
  uniformly distributed within a large
time period – target estimated milestone
  period \( (t_{pl}) \); at that, site workability is
  restored to required value only for a
  limited period of operation – till the next
  SR, and safety requirements may be not
  fulfilled in full scope;
- in the second case, all cumulative CR
  costs are attributed to the certain year
  (optimal from the point of view of total
  SR for the \( t_{pl} \) period, however workability
  and resource after CR are restored for
  the whole target estimated milestone
  period \( (t \geq t_{pl}) \)); also, maximum possible
decrease of industrial risk obtained by
repair methods is provided;
\[\text{• the problem of defining optimal terms}
\]
and scenarios (from SR or CR alternatives) over
rather large forecasting periods can be solved
individually for each object using a condition of

\[\text{Fig.1. General algorithm of assessment substantiation for development of programs in the framework of the Gas Mains Diagnostics and Integrity Management System}\]
equality of total costs for alternative scenarios; this will be the only correct decision [9];

- in case of multiple objects \( O_{GTS} = \{O_1, \ldots, O_M\} \) the expediency of such calculation is doubtful owing to additional requirements and restrictions (beside above criteria of technical condition and integrity (1)), connected with unformalized (non-quantitative and non-analytical) factors reduced to a uniform indicator of ‘importance priority’ [3]); furthermore, such decision for the whole multitude may be not the only one;

- considering the above, the problem, as formulated in Methodological guidelines, is reduced to ranging the objects of multitude \( \{O_1, \ldots, O_M\} \) within the planning year in accordance with hierarchical system of \( p, Q, S, \lambda, D \) indicators, so that summary expenses during the allocated period should be less than the established limit, and the effect of technical condition and integrity indicators would be of its maximal value:

\[
O_{GTS} = \min_{e} \min_{s} \max_{p, r} \{O_1, \ldots, O_M\}. \tag{2}
\]

The scheme of this process shown at fig. 2 depicts a case when all objects \( \{O_1, \ldots, O_M\} \) at the point of time \( t_0 \) possess sufficient (true and complete) information on the actual state of linear parts of gas mains (it is assumed that such initial condition is provided only by results of internal pipeline diagnostics (IPD)).

The scheme for the case without IPD leads to reduction of estimation analysis in terms of reliability indicators (failure probability is not defined with reliability comparable with similar estimation for the case with IPD).

To avoid both a methodological collapse in solving this problem and reference to poorly justified approximate calculations of reliability indicators in the decision-making hierarchy, evaluation of industrial risk indicators shall be used as a single unifying criterion, e.g. within the independent pairs ‘specific cumulative industrial risk – specific expected damage’ or ‘specific frequency of failures – specific expected damage’.

This approach has been adopted partly because the assessment of specific frequency of failures at Gazprom JSC facilities is standardized [10] by now. Assessment methodology is built on results of factorial analysis of influence on specified indicator of both object operation and maintenance quantitative parameters, its technical condition, and factors of natural and economic environment, taking into account also organizational and qualification

Fig. 2. The scheme of decision-making for TGP LP facilities at availability of sufficient data about defects (\( k_{CR} \) – criterion for capital repair of the long-distance section of a gas main linear part; share of pipes to be replaced)
features of personnel. Failures frequency estimation on the basis of document [10] does not depend directly on defects revealed at diagnostics, and, hence, is comparable methodically with both analysis at availability of IPD and that excluding it.

Primary analysis of risk indicators, and checks of acceptability criteria in accordance with admissible/acceptable risk matrix (in Methodological guidelines a ‘continuous scale’ option is proposed – fig. 3) make it possible to reveal any obvious safety ‘bottlenecks’ in any linear parts of gas mains. As a rule, these are the parts of increased expected damage in case of failure. Subsequent (compulsory) analysis of technical condition and reliability indicators, beside the objectives of defining the optimal term of restoring activities (SR – CR, if necessary) and their volumes (repair of all defective pipe sections meeting SR – CR requirements) taking into account revealed anomalies of industrial risks initiates the estimation of these activities from the point of view of decreasing such risk to acceptable level. In the case when SR – CR methods (after elimination of all defects, and restoration of reliability and resource to design values) do not provide a positive result for risk, then reconstruction mechanisms should be applied (increasing site category, using pipe sections with thicker walls or increased strength materials, site relocation, etc.), or the requirement to decrease permissible working pressure should be introduced.

At realization of Methodological guidelines, it is necessary to evaluate the whole complex of all potential scenarios for each object, if this is connected with CR carrying over (shifting) to subsequent – in relation to the first optimal year – periods. At that, there would occur SR emerging from previous to the year of specified CR periods (fig. 4).

On fig. 5–9, and in the table below, selective analysis of long-distance gas main (600 km) is given, focusing on mismatch condition of industrial risk indicators on 9 of 30 sites. At that, the situation of inefficient initial planning has been revealed in connection with reliability indicators – on a number of sites CR could be shifted to later periods, while on other sites it was necessary to initiate their earlier execution.

Application of these Methodological guidelines has already given a notable result even in the limited planning scope of Gazprom TGP LP diagnostics, maintenance, and repair in the framework of realization of the Program for comprehensive overhauling of the linear part of Gazprom’s gas trunklines for the period from 2011 to 2015. This new ‘toolkit’ allowed to increase the efficiency of making technical and administrative decisions due to increased forecast accuracy and

![Fig. 3. Specific cumulative industrial risk matrix](image-url)
Fig. 4. Scenarios and recalculation of total cost limit criterion

<table>
<thead>
<tr>
<th>Scenario</th>
<th>1st year</th>
<th>2nd year</th>
<th>3rd year</th>
<th>4th year</th>
<th>5th year</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>C0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>No activities required</td>
</tr>
<tr>
<td>C1</td>
<td>SR</td>
<td>SR</td>
<td>SR</td>
<td>SR</td>
<td>SR</td>
<td>Selective repair is optimal</td>
</tr>
<tr>
<td>C2-1</td>
<td>CR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Capital repair is optimal</td>
</tr>
<tr>
<td>C2-2</td>
<td>SR</td>
<td>CR</td>
<td></td>
<td></td>
<td></td>
<td>Scenarios C2-2 – C2-5 provide a possibility of reducing costs in the required year by carrying over CR to next years with increase of total expenses for all years of the Program</td>
</tr>
<tr>
<td>C2-3</td>
<td>SR</td>
<td>SR</td>
<td>CR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C2-4</td>
<td>SR</td>
<td>SR</td>
<td>SR</td>
<td>CR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C2-5</td>
<td>SR</td>
<td>SR</td>
<td>SR</td>
<td>SR</td>
<td>CR</td>
<td></td>
</tr>
</tbody>
</table>

Scenarios C0, C1, C2-2 – C2-5 can be supplemented by carrying out diagnostic inspections (at expiration of 5 or 2 years since previous IPD for sites with stress corrosion cracking) and pressure decrease.

Fig. 5. Specific cumulative industrial risk for ‘inter-valve’ sites, kRUR/(km·year)

Fig. 6. Cumulative industrial risk for ‘inter-valve’ sites, kRUR/(km·year)
Fig. 7. **Cumulative industrial risk**

![Cumulative industrial risk graph](image)

- Without repairs in 2014–2015
- Taking into account the 100%-execution of cumulative capital repairs Program for 2011–2015
- Planning repair works to achieve target indicators by 2015
- Target level

Fig. 8. **Probability of failures at ‘inter-valve’ sites**

![Probability of failures graph](image)

- Site numbers: 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30
- Repair required
- Diagnostic inspection required

Fig. 9. **Cumulative indicator of technical condition**

![Cumulative indicator graph](image)

- Site numbers: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30
- CR required
- Repair works performed
- Program (2013–2015)
- Offers to the Program for 2016–2020
- Not expected till 2020
reliability in assessment of technical conditions and risks at operation of gas-transportation systems, target financing to maintain the required technical condition on the basis of GTS ranging by importance and threats, designation optimality of GTS objects, terms and volumes of maintenance and repair programs taking into account cost limits and clear targeting to achieve maximum potential reliability and safety indicators for the whole GTS.

**Values of technical condition indicators**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>2010</th>
<th>Target value, up to</th>
<th>2013 (plan)</th>
<th>2013 (actual)</th>
<th>2015 (plan)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific cumulative industrial risk, kRUR/(km·year)</td>
<td>260.0</td>
<td>12.5</td>
<td>94.8</td>
<td>94.6</td>
<td>68.6</td>
</tr>
<tr>
<td>Failure probability ( P )</td>
<td>0.864</td>
<td>0.010</td>
<td>0.358</td>
<td>0.358</td>
<td>0.315</td>
</tr>
<tr>
<td>Cumulative technical state indicator</td>
<td>&gt; 0.06</td>
<td>0.06</td>
<td>&gt; 0.06</td>
<td>&gt; 0.06</td>
<td>&gt; 0.06</td>
</tr>
<tr>
<td></td>
<td>for 12 of 30 “inter-valve” sites ( P_{IPDP} = 0.0566 )</td>
<td></td>
<td>for 10 of 30 “inter-valve” sites ( P_{IPDP} = 0.0565 )</td>
<td>for 10 of 30 “inter-valve” sites ( P_{IPDP} = 0.0597 )</td>
<td>for 7 of 30 “inter-valve” sites ( P_{IPDP} = 0.0384 )</td>
</tr>
<tr>
<td>Cumulative industrial risk, kRUR/year</td>
<td>132 413</td>
<td>6 366</td>
<td>48 259</td>
<td>48 167</td>
<td>34 952</td>
</tr>
</tbody>
</table>

**References**

2. Concept of GTS Facilities Technical Condition and Integrity Management with Account of Transportation Tasks / Gazprom JSC. – 2011.
3. R Gazprom 2-2.3-691-2013. Methodology of Forming Technical Diagnostics and Repair Programs for Linear Sections of UGSS Gas Mains of Gazprom JSC.
4. R Gazprom 2-2.3-692-2013. Regulations of Forming Technical Diagnostics and Repair Programs for Sections of UGSS Gas Mains of Gazprom JSC.
5. GOST 18322-78. The System of Equipment Maintenance and Repair. Terms and Definitions.
9. Recommendations for Accounting of Technical, Natural Climatic, and Other Impacts at Diagnostics.