ANALYSIS AND ASSESSMENT OF A TECHNICAL FAILURE IN A GAS PIPELINE AND ITS IMPACT ON THE OPERATION OF THE ROMANIAN GAS SYSTEM

Assoc. Prof. PhD, **Adina TĂTAR**, University "Constantin Brâncusi" of Târgu Jiu, Faculty of Engineering, adynatatar@gmail.com
Lecturer, PhD, Eng. **Ioan Lucian DIODIU**, Lucian Blaga University of Sibiu, Department of Computer Science and Electrical Engineering, ioanlucian.diodiu@ulbsibiu.ro
Lecturer, PhD, Eng. **Adriana ZAMORA**, University of Petrosani, Mechanical Engineering, Industrial and Transport Department, adrianazamora@upet.ro
Lecturer, PhD, Eng. **Sorina Daniela STĂNILĂ**, University of Petrosani, Mechanical Engineering, Industrial and Transport Department, sorina_stanila@yahoo.com
PhD. Stud., Eng. **Florin MURESAN – GRECU**, University of Petrosani, Industrial Engineering Doctoral School, flomavon2002@yahoo.com
PhD, Eng. **Adrian Mihai SCHIOPU**, University of Petrosani, Strategic Studies of Energy Security Research Center, schiopu.adrian.mihai@gmail.com
Master's student, Eng. **Daria IONESCU**, University of Petrosani, Strategic Studies of Energy Security Research Center, daria.ionescu20@yahoo.com

ABSTRACT: *A technical failure in a gas pipeline represents an event with a significant impact on the safety and operation of the natural gas transmission system. The analysis and assessment of such a failure are essential for identifying the causes, limiting the effects, and preventing similar incidents in the future. Gas pipelines are part of the critical infrastructure of the Romanian Gas System, and any malfunction can affect the gas supply to both industrial and residential consumers. The process of analyzing a failure begins with identifying the type of defect and the circumstances under which it occurred. Common causes include pipeline corrosion, material defects, construction or installation errors, excessive pressures within the system, or unauthorized external interventions affecting the infrastructure. Technical evaluation involves inspecting the affected area, using diagnostic methods such as non-destructive testing, analyzing pressure and flow data, and reviewing the pipeline's maintenance history. The impact on the operation of the Romanian Gas System may vary depending on the severity of the failure and the position of the pipeline within the network. In the case of a main pipeline, the failure may lead to a reduction in system pressure, temporary interruption of supply to certain regions, or the need to redistribute gas flows through alternative routes. These measures can involve high operational costs and may affect the stability of energy supply. Furthermore, a failure may generate additional risks for the environment and public safety, especially if there are gas leaks or a risk of explosion. For this reason, the rapid intervention of specialized teams and the application of safety procedures are essential in order to limit the consequences. Following the technical analysis, an evaluation report is prepared, including the causes of the failure, the remedial measures taken, and recommendations to prevent similar situations. The implementation of rigorous monitoring programs, preventive maintenance, and infrastructure modernization contributes to increasing the safety and reliability of the Romanian Gas System in the long term.*

Keywords: Analysis, Assessment, technical failure, Gas system

1. INTRODUCTION

The safe and continuous operation of natural gas transmission systems represents a critical component of national energy security and economic stability. In Romania, the gas infrastructure plays a strategic role in ensuring the supply of energy to industrial consumers, households, and power generation facilities, while also contributing to regional energy interconnectivity. However, the complexity and extensive nature of pipeline networks expose them to various technical risks, including material degradation, operational errors, and external interferences, which may lead to system failures. Technical failures in gas pipelines can have significant consequences, ranging from local supply disruptions to large-scale imbalances within the national gas transmission system. Such incidents not only affect the physical integrity of infrastructure but also challenge the operational resilience, safety protocols, and emergency response capabilities of system operators. Furthermore, failures may generate cascading effects across interconnected networks, amplifying their impact beyond the immediate failure site. This study focuses on the analysis and assessment of a technical failure occurring within a gas pipeline and evaluates its impact on the operation of the Romanian gas system. The research aims to identify the root causes of the failure, examine the sequence of events leading to the incident, and assess the resulting operational, economic, and safety implications. Particular attention is given to system response mechanisms, including pressure management, supply rerouting, and coordination between transmission and distribution operators. By integrating technical analysis with system-level evaluation, this work seeks to contribute to a better understanding of failure dynamics in gas infrastructure and to support the development of improved preventive and mitigation strategies. The findings are intended to provide relevant insights for engineers, system operators, and policymakers involved in the management and modernization of gas transmission networks. [1]

2. CRITICAL ANALYSIS

Critical analysis consists of the following activities:

- identifying strategic cross-border gas pipelines classified as critical infrastructures with a role in ensuring energy and national security;
- identifying accident risk scenarios;
- assessment accident risk scenarios;
- developing a protection and safety strategy.

2.1. Identification of Cross-Border Gas Pipelines Infrastructures

Table 1 lists the critical infrastructures identified within the Romanian Gas System. [2-4]

Table 1. Critical Cross-Border Gas Pipelines Infrastructures

Owner	Responsible Authority	Name of Cross-Border Gas Pipeline
Transgaz Company	Ministry of Energy	Arad – Csanadpalota (Romania – Hungary)
		Iasi – Ungheni (Romania – Republic of Moldova)
		Giurgiu – Ruse (Romania – Bulgaria)
		Negru Vodă 1 – Kardam (Romania – Bulgaria)
		Negru Vodă 2 – Kardam (Romania – Bulgaria)
		Negru Vodă 3 – Kardam (Romania – Bulgaria)
		Mediesu Aurit – Tekovo (Romania – Ukraine)
		Isaccea 1 – Orlovka

		(Romania – Ukraine)
		Isaccea 2 – Orlovka (Romania – Ukraine)
		Isaccea 3 – Orlovka (Romania – Ukraine)

2.2. Risk Scenario Identification

The following risk scenario has been identified as having the highest probability of occurrence.

Risk Scenario: Technical Incident → Cross-Border Gas Pipeline – Total/partial shutdown of the Romanian Gas System

2.3. Risk Scenario Assessment

Sequential Progression

TECHNICAL INCIDENT → CROSS-BORDER GAS PIPELINE:

SEQUENCE OF TECHNICAL INCIDENTS / EXPLOSIONS / FIRES / WORKPLACE ACCIDENTS → OPERATOR (OPERATING PERSONNEL) ERRORS → TOTAL / PARTIAL SHUTDOWN OF THE NATIONAL GAS SYSTEM → ENERGY INSECURITY → ECONOMIC INSECURITY → NATIONAL INSECURITY → MATERIAL DAMAGE / LOSS OF HUMAN LIFE → STATE OF NATIONAL INSTABILITY

The causes and associated effects of the risk scenario are described in Table 2
The causes and associated effects of the risk scenario are described in Table 2

Table 2. Causes and Effects

Causes:	Effects
• poor condition, lack of investment, absence of inspections, incorrect or outdated configuration of: ➢ main gas pipelines (wall thickness); ➢ natural gas regulating and metering stations; ➢ valve control stations; ➢ natural gas measurement stations; ➢ natural gas compression stations; ➢ cathodic protection stations; • erroneous interventions by technical personnel; • lack of specialized and/or trained operational staff; • poor or missing communication with the National Natural Gas Dispatch Center; • inadequate human resources; • insufficient work procedures during periods of instability; • inadequate procedures in case of insecurity; • lack of personnel training aimed at preventing and eliminating sources of risk.	• the halting of the natural gas market between Romania, ENTSO-G, NATO, or other partner countries; • failure to supply natural gas to neighboring energy systems from ENTSO-G, NATO, or other partner countries; • failure to supply natural gas to consumers; • massive material damage resulting from the lack of natural gas; • significant damages caused by the dependence of other systems on natural gas; • potential power blackout.

Probability determination

In Table 3, the probability level was determined.

Table 3. Probability determination

Level		Probability definition	Periods
	1. Very low	It has a very low probability of occurring. Normal measures are required to monitor the evolution of the event.	over 20 years
	2. Low	The event has a low probability of occurring. Efforts are needed to reduce the probability and/or mitigate the impact produced.	16 – 20 years
	3. Medium	The event has a significant probability of occurring. Significant efforts are needed to reduce the probability and/or mitigate the impact produced.	11 – 15 years
X	**4. High**	The event has a high probability of occurring. Priority efforts are needed to reduce the probability and mitigate the impact produced.	**6 – 10 years**
	5. Very high	The event is considered imminent. Immediate and extreme measures are required to protect the target, evacuation to a safe location if the impact so requires.	1 – 5 years

Gravity (impact) determination

In Table 4, the vulnerabilities, capacities, and capabilities level was determined.

Table 4. Vulnerabilities, capacities, and capabilities determination

Vulnerabilities, capacities, and capabilities	Level
1. Lack of gas energy infrastructure in the northern part of the country: • lack of investments (new constructions of gas pipelines and regulating-measuring stations, valve control, measurement, compression, and cathodic protection) and/or failure to upgrade existing infrastructure; • unpredictability of the political system; possibility of interruptions in natural gas supply, whether regional or national, leading to: ➢ halting the natural gas market between Romania and ENTSO-G / NATO / partner countries; ➢ stopping electricity production from thermal power plants; ➢ failure to supply natural gas to industrial and household consumers. • energy insecurity, leading to economic insecurity, which in turn generates national insecurity.	1. Very low 2. Low 3. Medium 4. High **5. Very high**
2. Incorrect or poor configuration of gas energy infrastructure: • incorrect or poor configuration of pipelines (thickness); • incorrect or poor configuration of regulating and metering stations, valve control, measurement, compression, and cathodic protection.	1. Very low 2. Low 3. Medium 4. High **5. Very high**
3. The level of specialization and periodic training of personnel responsible for restoring the natural gas supply process: • operational staff within the National Natural Gas Dispatch Center; • operational staff at regulating and metering stations, valve control, measurement, compression, and cathodic protection stations; • maintenance personnel; • security personnel.	1. Very low 2. Low 3. Medium 4. High **5. Very high**

In Table 5, the impacts level was determined.

Table 5. Impact level determination

Impacts	Level
1. Major losses caused by the lack of natural gas.	1. Very low 2. Low 3. Medium 4. High **5. Very high**

2. Significant losses resulting from other systems' dependence on natural gas.	1. Very low 2. Low 3. Medium 4. High **5. Very high**
3. Potential damage to the underground environment (explosions and fires).	1. Very low 2. Low 3. Medium 4. High **5. Very high**
4. Loss of human lives – strong social impacts.	1. Very low 2. Low 3. Medium 4. High **5. Very high**

In Table 6, the gravity (impact) level was determined.

Table 6. Gravity (impact) determination

	Level	Gravity (impact) definition
	1. Very low	The event produces a minor disturbance in the activity, without material damage.
	2. Low	The event causes minor material damage and limited disruption to activity.
	3. Medium	Injuries to personnel, and/or certain losses of equipment, utilities and delays in providing the service.
	4. High	Serious personnel injuries, significant loss of equipment and facilities, delays and/or interruption of service provision.
X	**5. Very high**	The consequences are catastrophic resulting in deaths and serious injuries to personnel, major losses in equipment, facilities, and termination of service provision.

Risk determination

In the matrix below, the calculation of the risk level can be observed, which is the product of probability and gravity (impact).

PROBABILITY						
	Very high 5					
	High 4					**X**
	Medium 3					
	Low 2					
	Very low 1					
	0	**Very low 1**	**Low 2**	**Medium 3**	**High 4**	**Very high 5**
GRAVITY (IMPACT)						

Calculated risk level		
	Level	**Score**
	Very low	**1 – 3**
	Low	**4 – 6**
	Medium	**7 – 12**
	High	**13 – 16**
X	**Very high**	**17 – 25**

The risk scenario has the risk level **20 – Very high (Probability 4 x Gravity/Impact 5)**, and for this reason the risk is being treated with proposed recommendations (measures).

Risk treatment

In Table 7, is proposed mesures.

Table 7. Proposed measures

Vulnerabilities, capacities, and capabilities	Proposed measures
1. Lack of gas energy infrastructure in the northern part of the country.	a) Major investments in energy infrastructure: - New pipelines; - New regulating and metering stations, valve control, measurement, compression, and cathodic protection facilities; - Modernization of existing pipelines and regulating/metering stations, valve control, measurement, compression, and cathodic protection facilities – old ones. b) Predictability (stability) of the political system; c) EU funds for securing European critical energy infrastructures.
2. Incorrect or poor configuration of gas energy infrastructure.	Technical assessments (expert evaluations) of the appropriate thickness of pipelines for operation under normal parameters.
3. The level of specialization and periodic training of personnel responsible for restoring the natural gas supply process.	a) Specialized training for maintenance, gas, and rescue personnel; b) Investigation of technical incidents and workplace accidents, etc.; c) Maintaining installations at an optimal operational level.

After implementing risk mitigation measures, it results that, according with Table 8.

Table 8. Measures after risk treatment

Impacts	Identified	After the implementation of measures
1. Major losses caused by the lack of natural gas.	1. Very low	1. Very low
	2. Low	2. Low
	3. Medium	**3. Medium**
	4. High	4. High
	5. Very high	5. Very high
2. Significant losses resulting from other systems' dependence on natural gas.	1. Very low	1. Very low
	2. Low	2. Low
	3. Medium	**3. Medium**
	4. High	4. High
	5. Very high	5. Very high
3. Potential damage to the underground environment (explosions and fires).	1. Very low	1. Very low
	2. Low	2. Low
	3. Medium	**3. Medium**
	4. High	4. High
	5. Very high	5. Very high
4. Loss of human lives – strong social impacts.	1. Very low	1. Very low
	2. Low	2. Low
	3. Medium	**3. Medium**
	4. High	4. High
	5. Very high	5. Very high

Recalculation of consequences' gravity (impact)

In Table 9, is recalculation of consequences' gravity (impact).

Table 9. Recalculation of consequences' gravity (impact)

Level		Gravity (impact) definition
	1. Very low	The event produces a minor disturbance in the activity, without material damage.
	2. Low	The event causes minor material damage and limited disruption to activity.
X	**3. Medium**	Injuries to personnel, and/or certain losses of equipment, utilities and delays in providing the service.
	4. High	Serious personnel injuries, significant loss of equipment and facilities, delays and/or interruption of service provision.
	5. Very high	The consequences are catastrophic resulting in deaths and serious injuries to personnel, major losses in equipment, facilities, and termination of service provision.

Risk recalculation

In the matrix below, the recalculation of the risk level can be observed, which is the product of probability and gravity (impact).

PROBABILITY	**Very high 5**					
	High 4			**X**		
	Medium 3					
	Low 2					
	Very low 1					
	0	**Very low 1**	**Low 2**	**Medium 3**	**High 4**	**Very high 5**
GRAVITY (IMPACT)						

Recalculated risk level		
	Level	**Score**
	Very low	**1 – 3**
	Low	**4 – 6**
X	**Medium**	**7 – 12**
	High	**13 – 16**
	Very high	**17 – 25**

The risk scenario has the risk level **12 – Medium (Probability 4 x Gravity/Impact 3),** [1-5]

3. DEVELOPMENT OF THE SAFETY AND SECURITY STRATEGY FOR GAS PIPELINES WITHIN THE NATIONAL GAS SYSTEM

1. TECHNICAL MEASURES

1.1. Pipeline Integrity Assessment:

- Conduct a detailed structural and material analysis of the affected pipeline segment;
- Use techniques like ultrasonic testing, magnetic flux leakage, and pipeline smart pigging;

- Identify failure mode: corrosion, mechanical fatigue, weld defects, overpressure, or external interference;
- Implement real-time monitoring systems with SCADA integration to track;
- Pressure, flow rate, temperature, and gas composition;
- Early anomaly detection using AI or predictive maintenance tools.

1.2. Failure Containment and Mitigation:

- Automatic shut-off valves to isolate the affected segment;
- Deploy emergency pressure relief systems to prevent catastrophic failure;
- Implement a redundant pipeline route analysis to maintain gas supply continuity during repairs;

1.3. System Reliability Improvement:

- Upgrade older pipeline sections using high-strength materials resistant to corrosion and pressure cycles;
- Consider looping pipelines to provide alternative flow paths and reduce dependency on a single line;
- Integrate digital twins of the network to simulate failures and optimize response strategies.

2. ORGANIZATIONAL MEASURES

2.1. Roles and Responsibilities:

- Assign a Pipeline Incident Response Team (PIRT) with clearly defined responsibilities;
- Technical team: inspection, repair, and restoration;
- Operations team: flow rerouting and system stabilization;
- Communication team: stakeholder updates, regulatory reporting.

2.2. Coordination with Authorities - Collaborate with:

- National Gas Transmission Company (e.g., Transgaz);
- Local emergency services for containment and public safety;
- Regulatory bodies for reporting and compliance.

2.3. Training and Preparedness:

- Regular emergency drills simulating pipeline rupture scenarios;
- Cross-functional workshops for operational, technical, and safety staff;
- Maintain a knowledge repository of past failures, corrective measures, and lessons learned.

3. SAFETY MEASURES

3.1. Risk Assessment:

- Conduct Hazard and Operability Study (HAZOP) for pipeline segments;
- Evaluate potential impact radius of gas leaks and pressure surges;
- Model worst-case scenarios to determine evacuation zones and emergency shutdown sequences.

3.2. Personal and Public Safety:

- Equip personnel with gas detectors, flame-retardant clothing, and emergency breathing apparatus;
- Implement early warning systems for nearby communities;

- Establish evacuation and emergency response protocols aligned with local safety regulations.

3.3. Preventive Maintenance:

- Schedule periodic inspections and corrosion control programs;
- Introduce chemical inhibitors or coatings to reduce internal and external corrosion;
- Ensure pressure relief valves and shut-off mechanisms are regularly tested.

4. SECURITY MEASURES

4.1. Physical Security:

- Fencing, surveillance cameras, and access control for critical pipeline sections;
- Patrols in high-risk or remote areas prone to vandalism or sabotage.

4.2. Cybersecurity:

- Protect SCADA and monitoring systems from cyberattacks;
- Use encryption, multi-factor authentication, and network segmentation for critical systems;
- Develop incident response protocols for cyber intrusion affecting pipeline operations.

4.3. Supply Chain Security:

- Vet contractors and suppliers to ensure integrity of maintenance materials and equipment;
- Monitor fuel, chemicals, and repair parts to avoid tampering.

5. INTEGRATION AND CONTINUOUS IMPROVEMENT

Implement a feedback loop:

- Post-incident review → lessons learned → update technical, organizational, safety, and security protocols;
- Use simulation and modeling tools to predict impacts of potential future failures on the Romanian gas system;

Encourage stakeholder engagement, including regulatory authorities, customers, and emergency services, to ensure holistic resilience. [6]

4. CONCLUSIONS

The analysis and assessment of the recent technical failure in the Romanian gas pipeline system underscore the critical interdependence between infrastructure integrity, operational continuity, and public safety. The failure highlighted vulnerabilities in both the physical assets and the organizational procedures governing the gas network, emphasizing the need for a multi-layered approach to risk management.

From a technical perspective, systematic pipeline integrity assessments, real-time monitoring, and predictive maintenance are essential to identify potential failure modes—ranging from corrosion and mechanical fatigue to weld defects or external interference—before they escalate into operational disruptions. Implementation of automated containment measures, redundant routing, and digital twins further enhances system resilience, ensuring continuity of gas supply during maintenance or emergency interventions.

Organizational measures complement technical efforts by defining clear roles and responsibilities through a Pipeline Incident Response Team (PIRT), fostering effective coordination with regulatory authorities and local emergency services, and ensuring personnel are trained through drills, workshops, and knowledge-sharing mechanisms. These measures collectively strengthen operational readiness and decision-making during critical incidents.

Safety and security remain paramount. Hazard analyses, preventive maintenance, personal protective equipment, early warning systems, and evacuation protocols reduce risk to personnel and communities. Simultaneously, physical security, cybersecurity, and supply chain integrity measures safeguard the system against deliberate threats, ensuring both physical and digital continuity of operations.

Finally, integrating these measures within a continuous improvement framework allows the Romanian gas system to learn from each incident, adapt procedures, and simulate potential future failures. This holistic strategy—combining technical, organizational, safety, and security initiatives—provides a robust foundation for enhancing the reliability, safety, and resilience of the national gas network, minimizing the operational and societal impacts of any future pipeline disruptions.

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