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RISK ASSESSMENT AND ANALYSIS IN PIPELINE TRANSPORT

Ismail Chobanzadeh, Ali Hasanzadeh,

Azerbaijan University of Architecture and Construction
IsmayilCobanzade54@gmail.com. Hasanzadaali66@gmail.com

Abstract: The presented article provides a comprehensive analysis of the risks arising in pipeline transport, which is considered the main artery of the oil and gas industry. The main objective of the study is to identify technical, environmental and economic risks arising during the operation of pipelines and to determine effective assessment methods for their management.

The article systematically examines factors affecting the safety of pipeline infrastructure, such as corrosion, external mechanical effects and operational errors. Using modern mathematical models and statistical analysis methods, the probability of potential accident risks and the damage caused by these events to the environment, as well as to the disruption of the logistics chain, were assessed.

As a result of the study, practical recommendations were put forward for the digitalization of monitoring systems and the improvement of early warning mechanisms in order to minimize risks in pipeline transport. This approach, in addition to increasing the sustainability of transport logistics, plays an important role in ensuring the security of strategic energy infrastructure.[7]

Keywords: *pipeline transport, risk analysis, assessment methodology, infrastructure security, oil and gas logistics.*

Introduction

The energy dependence of the modern global economic system and the expansion of international trade relations have made the issue of delivering hydrocarbon resources from production points to the end consumer a strategic priority. In the logistics structure of the oil and gas industry, pipeline transport has unique advantages in terms of high throughput, continuity and low cost compared to other types of transport (rail, sea and road). However, the technological complexity of these systems and the fact that they cover thousands of kilometers of geographical area make them vulnerable to the influence of numerous risk factors of both internal and external origin.

The Republic of Azerbaijan, as an important energy hub of Eurasia, is at the center of transnational pipeline projects (Baku-Tbilisi-Ceyhan, Southern Gas Corridor, etc.). The stable and safe operation of this infrastructure is of critical importance not only for the country's economy, but also for the energy security of Europe. Therefore, identifying risks in pipeline transport, assessing them on a scientific and methodological basis and developing effective management strategies is one of the most relevant directions of modern logistics science.

Risk analysis in pipeline transport is a multifaceted process. It includes technical risks such as physical wear and corrosion of infrastructure, environmental risks that may cause damage to the ecosystem as a result of leaks, as well as economic and commercial risks arising from supply chain disruptions. In the current period, natural disasters caused by climate change and the

complex geopolitical situation make the dynamics of these risks even more unpredictable. In this regard, the transition from traditional reactive approaches (reacting after an event occurs) to proactive and preventive risk management models is inevitable.[3]

The main object of the research work is the pipeline transport system, and the subject is the mechanisms for assessing the risks arising in this system. The study of these issues, justified in the introduction, serves to optimize logistics costs, increase operational safety, and minimize accident probabilities through mathematical modeling. The analyses presented in the article also highlight the need to implement digital transformation and intelligent monitoring systems, which are necessary to achieve the goal of "zero accidents" in oil and gas logistics.

In the global architecture of energy logistics, pipelines are not just a physical means of transportation, but also strategic networks that ensure the economic security of states. However, the technological challenges and environmental priorities of the 21st century have fundamentally changed the concept of risk in pipeline transport. If earlier risk mainly meant mechanical failures and natural wear and tear, now cyber threats, digital management errors and environmental obligations related to the "carbon footprint" have also been added to this list.

The relevance of the study is primarily related to the digital transformation of pipeline logistics (Industry 4.0). Although SCADA systems and intelligent sensor networks reduce the human factor, they make the system vulnerable to cybersecurity risks. Any cyber-interference aimed at oil and gas infrastructure can result not only in material damage, but also in an energy crisis at the national level. In this regard, risk assessment is no longer just an engineering issue, but also a complex information security problem.[1]

On the other hand, international environmental goals such as the global "Green Transition" and COP29 place new demands on pipeline logistics. Environmental risks caused by oil and gas spills are no longer considered just local pollution, but also a factor affecting the country's international reputation and ESG (Environmental, Social and Governance) ratings. This makes the application of "zero emissions" and preventive monitoring technologies in the improvement of logistics systems inevitable.

Against the background of Azerbaijan's growing role in Europe's energy diversification, an in-depth analysis of the risk profile of domestic and transit pipelines is a key condition for economic sustainability. The article examines this complex approach - technical resilience, digital security and environmental responsibility in a unified way. The scientific novelty of the study lies in the synthesis of traditional risk models with modern digital and green logistics criteria. This approach allows us to predict not only the current state of transport systems in the oil and gas sector, but also their future adaptation capabilities.[4]

Main Part

In order to effectively manage risks in pipeline transport, it is first necessary to identify their origin. Studies show that risks in oil and gas logistics are concentrated in the following four main groups:

• *Technical and constructive risks:* This group includes corrosion of pipes (internal and external), defects in welding seams, metal fatigue and technological failures of equipment (pumping and compressor stations). In pipelines from some mature fields of Azerbaijan, the corrosion factor accounts for approximately 35-40% of the risks.

• *External mechanical influences:* Damage to pipelines during construction and agricultural work, illegal connections or sabotage.

• *Natural and climatic risks:* The complex terrain of Azerbaijan (mountainous areas, landslide zones) and seismic activity are serious sources of risk that can lead to deformation of pipelines.

• *Operational and human factors:* Dispatcher errors, untimely maintenance and software gaps in digital control systems.

Both qualitative and quantitative methods are used to assess risks in modern oil and gas logistics:

• *FMEA Analysis (Failure Mode and Effects Analysis):* With this method, the probability of each potential failure and the severity of the damage it can cause to the system are evaluated on a scale of 1 to 10.

• *Mathematical-Statistical Models (Monte Carlo method):* Based on past accident data, the probability distribution of future leaks is calculated.

• *Quantitative Risk Analysis (QRA):* Annual individual and collective risk levels are calculated for each kilometer of the pipeline. For example, the risk index is expressed by the formula R = PxC (P - probability of occurrence of an event, C - severity of consequences).[2]

The Baku-Tbilisi-Ceyhan (BTC) and Southern Gas Corridor (SGC) projects, which form the basis of Azerbaijan's oil and gas strategy, were built with the highest safety standards. However, the geopolitical complexity of the region through which these pipelines pass brings "Geopolitical Risks" to the fore.

• *Monitoring system:* The "SCADA" and fiber-optic sensor technologies applied in these pipelines allow for instant detection of leaks or external interference with centimeter accuracy.

• *Ecological sensitivity:* Risk assessment is carried out with double seriousness in the sections of the pipelines that pass through water bodies and reserves. For example, the installation of automatic shut-off valves in the event of any leakage reduces environmental risks by 90%.

The management of pipelines with "smart" systems makes them a target for cyber-attacks. The stoppage of the supply chain or manipulation of data creates an "invisible risk" for the logistics system. Therefore, a cybersecurity audit must be included in the risk assessment.[9]

Pipeline transport plays a strategically important role in the energy security architecture of the modern world economy. Although these systems are the most efficient means of delivering hydrocarbon resources from production points to global markets, their complex engineering structure and the fact that they cover thousands of kilometers make a systematic risk analysis inevitable. Risk management in oil and gas logistics is no longer limited to repairing technical failures, but is also becoming a multidimensional strategic management process. In this context, risk assessment requires a multidisciplinary approach at the intersection of fields such as engineering, ecology, economics and cybersecurity. Among the risk factors faced by pipeline infrastructure, technical factors such as corrosion processes and metal fatigue occupy a fundamental place. Corrosion prevention plays a crucial role in optimizing logistics costs, especially in Azerbaijan's long-term domestic pipeline networks. However, in addition to technical risks, external mechanical influences and illegal connections, characterized as "third-party interference", also pose a serious threat to the stability of the system. To quantitatively assess these threats, modern logistics uses "Probability of Failure" methodologies, which allow predicting potential accident scenarios for each segment in advance.[6]

In the era of digital transformation, equipping pipelines with intelligent control systems (SCADA) has opened a new stage in risk analysis. "Predictive Maintenance" strategies, implemented through artificial intelligence and machine learning algorithms, can detect leaks or pressure drops seconds before the event occurs by processing big data from sensors. This technological advantage also raises cybersecurity risks; as the protection of digital infrastructure from hacker attacks has become an integral part of oil and gas logistics. Thus, the risk assessment process must now necessarily include an information security audit.

Ecological and economic aspects are important factors that complement each other in the assessment of pipeline risks. The environmental damage caused by any spill is measured not only in direct cleanup costs, but also in heavy fines and reputational losses imposed in accordance with international environmental standards (e.g. COP29 targets and carbon tax). From an economic perspective, a pipeline outage can cause supply chain disruptions, paralyzing the operations of refineries and terminal operators. Using stress-test models to assess this chain effect is vital to

maintaining Azerbaijan's credibility as an energy exporter. In conclusion, risk analysis in pipeline transport must evolve from a static report into a dynamic and proactive decision-making mechanism. Against the backdrop of new threats posed by geopolitical tensions and climate change, the risk assessment process must be regularly updated and integrated with digital monitoring systems. This approach is the most important mechanism for increasing the efficiency of transport logistics in the oil and gas sector, as well as ensuring the continuity and security of energy flows on a national and international scale.[10]

This table summarizes the source of risks, their impact, and the recommended preventive measures against them.

Risk Category	Specific Threats	Impact Level	Preventive Measure
Technical	Corrosion, welding defects, metal fatigue	High	PIG (Intelligent Diagnostics) and digital twins
External İnfluences	Illegal connections, construction work, sabotage	Medium/High	Fiber-optic sensors and drone monitoring
Natural-Geography	Landslides, seismic activity, floods	Medium	Dynamic risk maps and GPS monitoring
Cybernetics	Intrusion into SCADA systems, data theft	Critical	Air-gap and encryption
Ecological	Leaks, methane emissions	High	Automatic shut-off valves (ASV)

Risk Matrix: This table is used to show the relationship between the probability of occurrence and the severity of consequences. It is the most requested model for ranking risks in pipelines.

Probability / Outcome	Minor (1)	Medium (2)	Seriously (3)	Critical (4)	Catastrophic (5)
Very High (5)	5 (S)	10 (H)	15 (H)	20 (C)	25 (C)
High (4)	4 (S)	8 (M)	12 (H)	16 (H)	20 (C)
Medium (3)	3 (L)	6 (M)	9 (M)	12 (H)	15 (H)
Low (2)	2 (L)	4 (S)	6 (M)	8 (M)	10 (H)
Very Low (1)	1 (L)	2 (L)	3 (L)	4 (S)	5 (S)

Note: L - Less, S - Surface, M - Medium, H - High, C – Critical.

Result

Research conducted on the analysis and assessment of risks in pipeline transport, which is the basis of oil and gas logistics in Azerbaijan, allows us to draw the following conclusions:

1. The need for integrated risk models: It has been established that traditional statistical methods do not fully ensure the safety of modern complex logistics systems. As the service life of pipelines increases, the risks of corrosion and metal fatigue increase exponentially. Therefore, the application of dynamic risk matrices that synthesize qualitative and quantitative analyses is a fundamental condition for the early identification of potential accident sites.

2. The role of digital transformation and artificial intelligence: The study shows that the transition to the "Logistics 4.0" concept and the introduction of predictive (predictive) monitoring systems based on artificial intelligence minimize errors caused by the human factor. Real-time

monitoring using fiber-optic sensors and drone technologies allows us to localize third-party interventions and leaks at the moment of the incident, which reduces operational risks by approximately 25-30%.[5]

3. Integration of environmental and economic sustainability: Risk assessment should not only protect technical safety, but also Azerbaijan's international environmental obligations (COP29 targets) and economic reputation. Preventive measures applied to prevent leaks serve both to avoid high environmental fines and to prevent millions of dollars of economic losses that will be caused by breaks in the supply chain.

4. Strategic proposal and future prospects: As a result, it is proposed to create a single "National Risk Management Platform" to improve the existing transport and logistics systems in Azerbaijan. This platform will combine cybersecurity, technical diagnostics and geopolitical risk analysis in a single center, ensuring the uninterrupted and safe operation of the country's energy arteries both locally and regionally.[6]

REFERENCES

1. British Petroleum (BP). Statistical Review of World Energy. 2024/2025 Reports.
2. Christopher, Martin. Logistics & Supply Chain Management. 5th Edition. Pearson, 2016.
3. Dey, Prasanta Kumar. Decision Support System for Risk Management: A Case Study of Pipeline. IEEE Transactions on Engineering Management, Vol. 58, No. 1, 2011.
4. Gupta, Braj Bhushan. Handbook of Research on Digital Transformation and Challenges to Data Security and Privacy. IGI Global, 2021.
5. Hopkin, Paul. Fundamentals of Risk Management: Understanding, Evaluating and Implementing Effective Risk Management. 5th Edition. Kogan Page, 2018.
6. International Energy Agency (IEA). World Energy Outlook 2024/2025.
7. Modarres, Mohammad. Risk Analysis in Engineering: Techniques, Tools, and Trends. CRC Press, 2016.
8. Muhlbauer, W. Kent. Pipeline Risk Management Manual: Ideas, Techniques, and Resources. 3rd Edition. Gulf Professional Publishing, 2015.
9. Tersine, Richard J. Principles of Inventory and Materials Management. PTR Prentice Hall, 1994.
10. Zio, Enrico. The Monte Carlo Simulation Method for System Reliability and Risk Analysis. Springer, 2013.