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# Technical and economic impact of digital transformation in Azerbaijan's mining industry: A qualitative study

Ibrahim Niftiyev[1*]

[1] Department of International Economics and Business, Azerbaijan State University of Economics (UNEC), Istiglaliyyat str., 6, AZ1001, Baku, Azerbaijan
[*]Corresponding author's email: ibrahim.niftiyev@unec.edu.az

## Abstract

Since 1991, mining has continuously contributed more than 80% to the gross domestic product (GDP) in Azerbaijan and has achieved the status of a key economic sector. Today, the mining industry is driving digital transformation as it faces ever new challenges, and the government has a vested interest in remaining profitable in global markets. The main objective of this paper is to qualitatively analyze the technical and economic impact of the ongoing digital transformation in Azerbaijan's mining industry. This analysis is conducted through a six-stage thematic analysis (TA) of expert interviews ($n$ = 7) conducted in July 2024. The results show that digital transformation in Azerbaijan's mining industry is progressing rapidly and holds significant potential for economic and technological advancements that could benefit the entire economy, albeit on a limited scale. There are specific technologies that improve operational efficiency and safety, with moderate economic impact. Despite the efficiency and productivity driven by private and multinational companies (MNCs), the country's long-term economic dependence on the mining sector needs to be reduced. This topic has not yet been thoroughly explored in academia, making the findings valuable for both researchers and policy makers seeking deeper insights into the digital transformation of Azerbaijan's mining industry.

## Keywords

Azerbaijani economy, Digital technologies, Mining industry, Thematic analysis

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## Introduction

Digital transformation refers to the integration of digital technologies into all aspects of an organization, fundamentally changing the way it operates and delivers value to its customers [1]. In the mining industry, digital transformation can involve the adoption of advanced technologies such as automation, data analytics and the Internet of Things (IoTs), which can improve operational efficiency, safety and productivity [2]. For example, plant automation and predictive maintenance enabled by IoT can reduce

downtime and operating costs [3]. In addition, data analytics can provide valuable insights for decision-making, improving resource management and optimizing supply chain processes [4, 5].

The mining industry in Azerbaijan is a crucial sector for the country's economic growth and contributes significantly to GDP [6]. This industry is primarily focused on the extraction of hydrocarbons, but it also includes valuable minerals such as gold, copper and iron ore [7]. Azerbaijan has made substantial investments in modernizing its mining sector and is using advanced technologies to improve productivity and environmental sustainability [8]. The government's strategic roadmap for the development of the mining industry even emphasizes the importance of digital transformation and innovation [9]. Despite this progress, there are still challenges such as regulatory frameworks, environmental concerns and the need for skilled labor [10]. Another challenge is the insufficient research on the ongoing and upcoming digital transformation in this industry, creating a research gap that needs to be investigated using appropriate methods.

The main objective of the present study is to thematically analyze the main experiences, challenges and problems related to the technical and economic aspects of digital transformation in the Azerbaijani mining industry. Due to the insufficient number of publications, this seems to be a significant research problem in the literature. However, digital transformation is progressing rapidly and creating a development gap between advanced economies and developing countries. Therefore, the following research questions were developed for the study: What is the status of the ongoing technical and economic impact of digital transformation in the Azerbaijani mining industry? How can the rest of the economy benefit from the mining industry's experience with digital transformation? The research methodology is TA. The data source is seven expert interviews conducted via email. Considering all these research techniques and the topic, this paper contributes to the literature by filling a knowledge gap. While existing literature on Azerbaijan's extractive industries primarily focuses on macroeconomic indicators such as oil price volatility and revenue management, this research addresses a critical gap by moving beyond traditional cost-benefit frameworks. Its novelty lies in a qualitative approach, gathering rare expert insights and analyzing them within the mining sector to provide a more nuanced understanding of the broader impact of digital transformation on the industry. The paper examines expert perceptions in depth to offer a more analytical perspective on the future.

## Method

A topic, narrowly defined as the digital transformation in the Azerbaijani mining industry, requires a special approach to the data source and the research methodology to be used in order to obtain valid empirical results. Typical econometric or statistical analyses may not provide a conclusive picture in the context of the assumed research question, as they use public data, which can be quite limited. Unnecessarily favoring

common statistical analysis may lead to biased and distorted results due to data errors [11, 12]. This study requires specific knowledge about a particular industry and several subsectors (e.g., crude petroleum, natural gas, gold, silver) that cannot be analyzed with conventional statistical data or document analysis. Therefore, a qualitative research design based on expert opinions is helpful to conduct this focused yet comprehensive study and to gain innovative insights.

To briefly describe the qualitative sample: three experts are economists with extensive knowledge and experience in the extractive industry; two experts are engineers who have followed the technical and technological changes in this industry since the early 2000s – including the digital aspects; finally, two experts are business consultants with experience in advising various MNCs in Azerbaijan when they were on the cusp of investing in the respective mining sectors. On average, each expert has more than twenty years of professional experience. The economists worked mainly in academia and had no administrative responsibilities (i.e., they were lecturers). Both the engineers and the consultants held managerial positions (e.g., head of department, assistant to the regional director). All interviews were conducted in English. The questions were structured to save time and avoid unnecessary complications during the interview. The collected data were coded qualitatively following the widespread and common experience in TA [13 – 15]. The questions asked were as follows:

1. How do you define digital transformation in the context of the mining industry in Azerbaijan?
2. What digital technologies are currently being used in your operations?
3. How have these technologies improved operational efficiency and safety?
4. Can you give examples of how digital transformation has improved resource management and extraction processes?
5. What technical challenges have you faced in implementing these digital technologies?
6. How has digital transformation impacted the economic performance of your mining operation?
7. How have digital technologies impacted the labor market in the mining industry (e.g., displacement of jobs, creation of new roles)?
8. What investment strategies have been used to fund digital transformation initiatives?
9. How do you see the return on investment (ROI) for digital transformation in the mining sector?
10. What are the economic risks and benefits associated with digital transformation in mining?
11. How has digital transformation impacted the decision-making processes in your company and what organizational changes were necessary to support it (e.g., training, restructuring)?
12. How has digital transformation impacted your competitive position in the industry?

13. What partnerships or collaborations have been critical to the digital transformation of the mining industry?
14. Do you think the ongoing digital transformation can be beneficial for the rest of the economy?

Expert interviews can be complex and revealing when it comes to analyzing unexplored topics. TA contributes significantly to the understanding of such qualitative data as it is a flexible, adaptable and rigorous methodology [16]. TA is based on the premise that researchers generate knowledge that reflects contextual truths and enables them to understand different perspectives on a given topic [16]. Most importantly, TA is helpful in identifying and categorizing the overlapping aspects of expert opinions in order to develop strong arguments for the research objective [17]. Specifically, this study uses Braun and Clark's six-step TA protocol, in which familiarizing with the data, generating initial codes, searching for themes, reviewing potential themes, defining and naming themes, and writing the report form the main part of the analysis [18].

Figure 1 illustrates the analytical framework of the research design. Essentially, the mining industry was observed from a technical and economic perspective in order to determine the necessary research objective and research question. Subsequently, appropriate and optimal decisions were made regarding data collection and methodology. Since the decision was made in favor of expert interviews, experts were needed to create the data set. The potential experts were screened using social media, mass media and personal contacts of the author, which eventually led to the email interviews in the fifth phase. Finally, as described above, the TA was conducted based on Braun and Clark's (2013) six-stage framework using Quirkos (version 2.5.3), a computerized (or assisted) tool for qualitative data analysis (QDA). The overall reporting style is similar to Montrone et al. [19] where the authors reported thematic clusters of their expert interview findings.

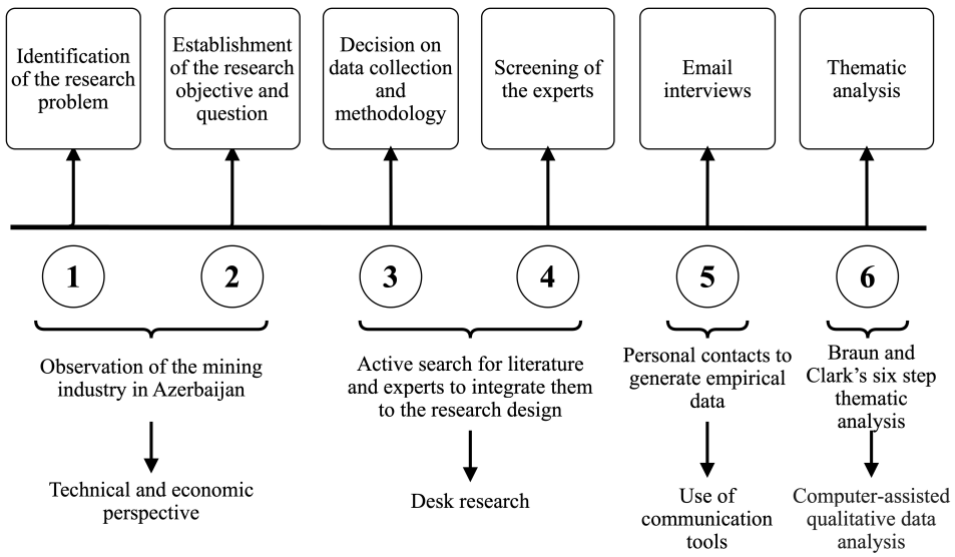


Figure 1. Analytical framework of the presented paper

In this study, particular attention was paid to the anonymity of the experts in order to generate genuine and reliable data, which is also recommended in the literature when power imbalances and the sensitivity of the topic require this [20, 21]. All experts consented to the use of their responses, with the option to withdraw their participation at any stage of the research until the study was submitted. The main principles of the Charter of Fundamental Rights of the European Union and the European Code of Conduct for Research Integrity were respected in the survey. Neither the author nor the experts disclosed any conflicts of interest.

## Results

### *Theme 1: Introduction of new digital technologies in the mining industry: why, what and where*

Based on the first five questions, the first theme of this TA can be constructed: "Introduction of new digital technologies in the mining industry: why, what and where", which mainly includes the opinions and ideas on the general reasons and motives for technological changes and modernization in the Azerbaijani mining industry, including digital transformation.

**Subtheme 1: Need for new technologies –** Most experts pointed out that the old mining technologies inherited from the Soviet Union failed to make the industry internationally competitive in the late 1990s and early 2000s. Sometimes these technologies were even dangerous to human life and the environment. Thus, after the collapse of the Soviet Union, it was also clear that the leading countries in the mining industry had more efficient and productive technologies that could not be imported during the years of the Soviet Union.

In a way, the introduction of new technologies, and more recently digital technologies, was inevitable from 1991 onwards. Digital technologies and technological modernization in general have significantly increased operational efficiency, as the offshore areas in the Caspian Sea were not yet deeply explored in the case of the oil and gas industry. In the processing of iron ores and non-ferrous metals, the old technologies were not able to achieve high percentage efficiency in ore grinding. Therefore, all experts agree that the modernized infrastructure has enabled Azerbaijan to compete on a global level, attract foreign investment and promote economic growth in the mining sector.

**Subtheme 2: Specific technologies in the mining industry –** Experts have recognized that automating machinery and equipment reduces human error and increases productivity, allowing more precise work to be performed more efficiently in the mining industry. Systems that monitor in real time and predictive maintenance technologies can detect equipment that is about to fail before it does. In addition, preventative technologies such as wearable devices for workers and remote-controlled machines improve on-site safety by eliminating the need for humans to be present in dangerous

locations and triggering real-time alerts in the event of a crisis situation. The use of remote operation centers for mining facilitates real-time monitoring and control of on-site operations. This in turn allows workers to perform their tasks from locations that are safer and more conducive to the working environment, leading to greater job satisfaction.

The experts were able to point out that in the early 2000s, mainly efficiency-enhancing technologies were imported and installed from European countries, while in the last 5 – 7 years the focus has been on digital technologies that make it possible to integrate both the pre-production and post-production phases. Two main directions emerged in the experts' answers: oil and natural gas related digital technologies and technologies for other mining subsectors. For example, if we talk about 3D imaging and 4D seismic data of the deep layers of offshore oil wells in the Caspian Sea, the pre-production phase now takes less time and is more cost-effective thanks to digital technologies. Monitoring wells in real time enables the measurement of drilling depth, ax load, pressure and the amount of solution injected. Digital systems also improve oil and gas extraction, processing and transportation. They allow equipment to be controlled from a single point in real time, improving operational efficiency. Video surveillance on offshore platforms and production sites ensures regular visual monitoring and better emergency management. In addition, hybrid drilling technology has been introduced in Azerbaijan, enabling more efficient drilling with higher penetration rates and lower costs.

The experts also pointed to several developments in the iron ore and ferrous metal subsectors of the mining industry that promise industry-wide developments. For example, the ongoing Geoinformation systems have begun collecting mine data, which will be effectively integrated with Azercosmos satellite services and allow Azerbaijan to optimize mining operations and production forecasts. Alternatively, new imported technologies such as "Carbon in Leach" will enable better iron ore processing and waste management in the Ganja-Dashkasan economic region. There are also plans to use "Direct Reduced Iron" and "Hot Briquetted Iron" technologies in mining. The experts mentioned that these technologies will be supported by digital technologies (e.g. digital twins of the plant assets, simulations, IoTs, predictive maintenance, cyber security) to increase their productivity in the near future.

Massive digitization is underway in the management and operation of back offices in the mining industry (i.e. office management systems, data storage, data management, etc.). Thanks to digital technologies, the post-production phase is more customer-oriented and feedback-based, which significantly improves quality control and future production planning. Digital technologies therefore automate processes and provide real-time data analytics to overcome the challenges of operational efficiency and safety.

**Subtheme 3: Technological gaps** – Although the mining industry in Azerbaijan is becoming increasingly digital and innovative, there are still some challenges, according to the experts. They spoke of a desirable situation in which the application of artificial

intelligence (AI) and machine learning would be more widespread, as the scope of application of these technologies is currently still very small and is a pilot project. Without data-driven decision-making, operational efficiency and costs associated with resource extraction cannot be maintained. In addition, a greener and smarter mining industry will help Azerbaijan achieve the Sustainable Development Goals (SDGs). Identifying gaps in technology is absolutely necessary, and the government's "Smart Industry Readiness Index" can be a useful tool.

**Subtheme 4: Challenges** – The experts also discussed the current and past challenges faced by the mining industry in the context of digital transformation. The introduction of digital technologies in the Azerbaijani mining industry brings with it a number of challenges that need to be carefully managed. According to the experts, one major problem is the existing infrastructure, which may not be advanced enough to support the seamless integration of sophisticated digital systems. This can lead to substantial initial costs for upgrading equipment and implementing new technologies. In addition, the workforce in Azerbaijan's mining sector may face a steep learning curve, as many employees lack the necessary skills and training to use digital tools effectively. For a long time, the average age of engineers in the mining industry was over 45 – 50 years, but recently the workforce has become significantly younger. This requires significant investment in education and training programs, which can be both time-consuming and costly. Lastly, cybersecurity vulnerabilities, outdated regulations, stakeholder resistance and potential workforce displacement are challenges to digital transformation in the Azerbaijani mining industry that require robust security measures, updated regulatory frameworks, change management strategies and inclusive approaches to mitigate socio-economic impacts.

### *Theme 2: Beyond simple cost and benefit analysis: economic aspects*

Most experts stated that they do not have accurate data or information on how digital technologies have changed the industry for the better in terms of costs and benefits. They based their arguments on publicly available reports, media content and their own observations. In other words, assessing the economic impact of digital transformation was a challenge for the experts, but they shared some brief ideas, illustrated by the subthemes below.

**Subtheme 1: Changes in economic performance** – Without much technical and mathematical detail, the experts were able to base their arguments on observations and unanimously pointed out that digital transformation is boosting economic performance in mining at both company and industry level. Benefits include higher resource extraction per unit of spent energy, shorter run times for upstream projects, shorter unplanned downtime, high asset optimization and better resource allocation. Such activities increase the likelihood of attracting further investment and improving competitiveness in the near future. In their answers, the experts hardly mentioned any economic risks that could be part of this theme, but they said that sunk costs are always present in any industry undergoing digital transformation. To maximize benefits and

minimize costs, it is important to focus on high ROI technologies, build partnerships, develop capabilities, leverage government support and start small.

**Subtheme 2: Impacts on labor** – Experts pointed out that digital technologies and change are having a significant impact on the workforce in the mining industry in Azerbaijan by reshaping tasks and skill requirements. On the one hand, this is unavoidable due to the constant pressure of international markets, while the dominance of MNCs is creating a competitive labor market segment.

Nevertheless, the reaction of the younger generation to such incentives is strong and they show a high adaptability to the new demands of the labor market. For example, we know that automation and robotics reduce the need for manual labor in hazardous tasks, which increases worker safety, but also requires retraining and upskilling of the workforce to operate and maintain modern machinery. Thanks to the invited foreign experts, workers in the mining industry are constantly being trained and retrained. Ultimately, the workers acquire the necessary knowledge and skills to perform their work.

However, this change also brings challenges, such as the possible relocation of jobs and the need to constantly upskill to keep up with rapidly evolving technological advances. Some mass layoffs can be observed from time to time, but these can hardly be linked to the unemployment (or tech unemployment) caused by the digital transformation.

**Subtheme 3: Financing digital transformation and reaping benefits –** Foreign capital and knowledge mainly help to adopt new digital technologies. Exhibitions and international relations are very much alive in the Azerbaijani mining industry, but domestic capabilities to drive technological change are limited. This has also led to limited spillover effects between industrial subsectors. Funding may therefore come mainly from the MNCs or the SOEs, while the benefits can be measured through improved firm-level indicators such as profitability and macro-economically through the oil revenues that find their way into the national economy. The main opinion of the experts on ROI was that the ROI is high in the short term, but that in the long term the overall economy cannot fully benefit from the digital transformation due to weak spillover effects.

**Subtheme 4: Mining and the rest of the economy –** In contrast to agriculture and the service sector, the technological equipment and knowledge in the industrial sectors are only applicable to a limited extent. For example, if a company acquires a new, cutting-edge technology for gold mining, it is likely to be used mainly in this subsector. Notwithstanding, the digital transformation that the mining industry is currently undergoing may spill over into other sectors such as the chemical industry, benefiting a wider area of the economy than just one part of it.

### *Theme 3: Organizational changes thanks to digital transformation*

**Subtheme 1: Changes in companywide realities –** Experts believe that digital transformation has profoundly impacted decision-making processes in many

organizations by providing real-time data analytics that enable more informed and agile decisions. In fact, Azerbaijan is exporting to countries it has not exported to before (e.g., Switzerland, Taiwan). New markets require new solutions to business problems, which can be provided by digital transformation.

Extensive training programs are in place to ensure that employees can use the new digital tools and technologies effectively. This has created a culture of training and development among mining companies, which are mainly focused on oil and gas. In addition, organizational restructuring has been necessary to create a more collaborative environment where IT specialists are integrated into traditional mining teams to bridge the gap between technology and operational expertise. This change has improved the ability to anticipate market trends, optimize resource allocation and respond quickly to operational challenges.

**Subtheme 2: New and old competition and partnerships –** Experts believe that digital transformation is essential for Azerbaijani mining companies to compete with other post-Soviet companies. Partnerships with leading ICT companies will help integrate new technologies, increase profitability and align with the SDGs to strengthen the role of the mining industry in greening the Azerbaijani economy.

## Conclusion

Historically, mining has played a key role in Azerbaijan's economic growth. As it plays a crucial role in creating high added value in the national economy, the government and MNCs are keen to use innovative technologies to drive digital transformation. This includes oil, natural gas, extraction of gold, iron and precious metals, etc. However, academia has not yet undertaken a detailed and systematic assessment of the status of the industry from a digital transformation perspective. This paper aims to fill this knowledge gap through TA from seven experts closely associated with the mining industry and provide specific information for further analysis.

Three main themes and ten subthemes were constructed from the qualitative data set, which consisted of 14 structured questions:

1. Introduction of new digital technologies in the mining industry: Why, what and where;
2. Beyond simple cost and benefit analysis: economic aspects;
3. Organizational changes thanks to digital transformation.

Based on the description and synthesis of the qualitative data, these three themes show that the mining industry in Azerbaijan is undergoing a digital transformation that increases the quality and quantity of industrial production. Thanks to the digital transformation, the impact on the environment can be better managed, safety measures can be better controlled, and new technologies can be used. Experts pointed out that it is difficult to assess the economic impact of digital transformation in the Azerbaijani mining industry but acknowledged improvements in operational efficiency and workforce adaptability. While digital progress boosts business performance and

attracts investment, its benefits may be limited by weak spillover effects on the overall economy. Finally, experts believe that digital transformation has significantly improved decision-making in the Azerbaijani mining industry by providing real-time data analytics and enabled entry into new markets such as Switzerland and Taiwan. Extensive employee training and organizational restructuring have fostered a collaborative environment, while partnerships with leading ICT companies are seen as crucial to increasing the sector's competitiveness, profitability and sustainability.

The findings of this study show above all the need for an integrative approach to economic policy. This means that the experience gained in the mining industry with regard to the digital transformation should also be transferred to other sectors. This requires balanced macroeconomic management, a stronger role for private companies and more academic input that have been mentioned in the literature [22, 23]. The current geopolitical challenges offer Azerbaijan optimal foreign policy conditions to gain a competitive advantage, which requires an appropriate exchange rate and trade policy [24, 25]. Also, cutting-edge research in digital innovation and the Azerbaijani economy suggests remaining open to new digitalization trends that align with environmental responsibilities [26–28].

This study is a great attempt to investigate digital transformation in the mining industry, but there are some limitations related to the research design. First, a more precise categorization of mining industry subsectors would be conceptually more useful. Second, a larger sample of experts would yield a more productive TA. Third, structured email interviews cannot capture the complexity of specialized expert knowledge about specific economic sectors. It is recommended to apply semi-structured, face-to-face and in-depth interviews, as well as additional QDA techniques and methods such as Grounded Theory or Qualitative Comparative Analysis to broaden the scope of similar future studies. It is therefore recommended that future studies should take the above aspects into account in order to be more comprehensive and methodologically sophisticated.

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