JOURNAL OF MANAGEMENT AND BUSINESS SOLUTIONS

Design of an Integrated Simulation Model and Managerial Scenario Analysis for Enhancing Productivity in Mining and Mineral Industries Organizations Using a System Dynamics Approach

1. Mohammad. Homayuni: PhD Student Department of Industrial Management, Qa.C., Islamic Azad University, Qazvin, Iran
2. Davood. Gharakhani*: Assistant professor Department of Industrial Management, Qa.C., Islamic Azad University, Qazvin, Iran
3. Alireza. Irajpour: Assistant professor Department of Industrial Management, Qa.C., Islamic Azad University, Qazvin, Iran

*corresponding author's email: davoodgharakhani@iau.ac.ir

ABSTRACT

The present study aimed to design an integrated simulation model and managerial scenario analysis framework to enhance productivity in mining and mineral industries organizations using a system dynamics approach. In terms of purpose, the study was applied, and in terms of implementation, it was descriptive. In the quantitative phase based on structural equation modeling, the statistical population comprised experts and practitioners in the mining and mineral industries sector at the Iran Mineral Processing Research Center and its parent organization, the Iranian Mines and Mining Industries Development and Renovation Organization (IMIDRO). The sample size was estimated at 174 participants. For model simulation purposes, a 10-year time horizon was considered, as this horizon adequately captures a reliable historical trend and aligns with the strategic planning horizon of the National Iranian Copper Industries Company, which was selected as the spatial domain of the model. Moreover, changes in investment and technology in the mining industry typically manifest their impacts over periods of 5 to 10 years. To collect the required data at this stage, the necessary information was extracted from the official CODAL disclosure system and analyzed using Vensim PLE software. To identify and analyze effective strategies for achieving a desirable state, eight policy scenarios were defined, including the development of technological infrastructure, modernization of physical equipment, improvement of organizational structures, intelligent energy management systems, research and development activities, technical skills of the workforce, mine safety management programs, and support for the local community. The simulation results indicated that single-dimensional scenarios generate only limited improvements, such that the second to fifth scenarios achieved only a 3% to 7% improvement in utilization rates and profitability growth. In contrast, more comprehensive scenarios—particularly the sixth to eighth scenarios—yielded more meaningful outcomes, with the sixth scenario leading to a 17.7% increase in utilization rates and profitability growth. The sixth scenario also demonstrated the best performance in improving and accelerating labor productivity, and when combined with the seventh and eighth scenarios, it produced the maximum possible impact on total productivity. Overall, the findings indicate that productivity enhancement requires a comprehensive and systemic perspective. In other words, focusing solely on a single dimension is insufficient, and sustainable results can only be achieved when managerial actions are implemented coherently across multiple levels within the framework of an integrated macro-level policy. In general, the results suggest that integrated and multidimensional approaches are more effective than single-dimensional policies in improving productivity and performance in the mining and mineral industries sector. These scenarios also resulted in a 3% to 5% improvement in total productivity.

Keywords: Integrated model design; productivity determinants; mining and mineral industries organizations; managerial scenarios; system dynamics approach; structural equation modeling.

Article history:
Received 07 November 2025
Revised 01 December 2025
Accepted 29 January 2026
First Published 10 February 2026
Final Publication 22 December 2026

How to cite this article:
Homayuni, M., Gharakhani, D., & Irajpour, A. (2026). Design of an Integrated Simulation Model and Managerial Scenario Analysis for Enhancing Productivity in Mining and Mineral Industries Organizations Using a System Dynamics Approach. *Journal of Management and Business Solutions, 4*(6), 1-28. https://doi.org/10.61838/jmbs.175

Introduction

A mine is defined as a location where a valuable material is extracted, and it includes several types, such as subsurface mines (located underground and requiring drilling and extraction, such as oil), surface mines (located on the surface, such as salt), fusible mines (requiring smelting by fire to separate pure materials, such as limestone), and non-fusible mines (not requiring smelting by fire, such as agate and turquoise) (1). The mining and mineral industries sector is one of the vital pillars of economic growth in many countries, particularly in developing economies. This sector not only has a significant impact on gross domestic product but also plays a crucial role in employment generation, attraction of foreign investment, infrastructure development, and the provision of financial resources for various economic projects. The mining industry is currently at a critical juncture in which operational excellence is increasingly defined not only by profitability but also by commitment to and focus on productivity drivers (2). Given the growing importance of productivity in the mining and mineral industries sector, attention to its influencing factors can play a major role in improving production processes, economic performance, and the provision of national resources, leading to reduced exploration, extraction, and processing costs and increased profitability and value added. Mining and mineral industries, by integrating traditional information technology practices, employing efficient human resources, utilizing advanced machinery, embracing social responsibility regarding environmental impacts, and establishing sustainable practices, seek to create added value in national gross domestic product (3).

Various factors, including human errors, influence accidents and performance degradation in the mining industry, and such errors lead to reduced productivity. In contrast, training in skills such as teamwork and conflict resolution contributes to productivity improvement in mineral industries (4). The mining and mineral industries sector can accelerate national growth and development by supplying raw materials for production, generating employment, creating value added, and producing tax revenues. This outcome is influenced by appropriate policymaking in the sector and by evaluating the impacts and consequences of such policies on other economic sectors, thereby facilitating increased financial investment and productivity in mining and mineral industries. Attention to various factors within the supply chain of mining companies, through establishing collaborative relationships aligned with customer needs and synchronizing operational activities, can enhance performance in terms of efficiency, productivity, profitability, and overall competitiveness (5). The global economy is increasingly intertwined with technological development, and productivity shocks affect the duration and intensity of organizational business cycles (6). The impact of productivity on the economy is multidimensional and may stem from technological advances, policy changes, and global recessions (7).

One of the influential factors in the occupational conditions of employees working in mining and mineral industries organizations is organizational productivity. Productivity refers to the optimal utilization of resources and represents a combination of efficiency and effectiveness. Organizational productivity involves performing tasks correctly and applying scientific and practical measures to reduce costs and increase satisfaction among employees, managers, and consumers (8). Organizational productivity is a key concept in organizational management for optimizing interactions among organizational elements and refers to an organization's ability to efficiently and effectively utilize its resources (financial, human, equipment, time, etc.) to achieve defined objectives, namely maximizing output and optimizing service delivery (9). Performance improvement requires identifying strengths and weaknesses, which creates a foundation for targeted training and individual and organizational development, preparing employees for more critical and prominent roles. Organizational performance improvement primarily depends on human resources, and attention to this vast and latent resource fosters organizational growth and capability development (10). An organization that seeks performance improvement in human, financial, and process dimensions can deliver differentiated products and services and achieve a competitive advantage (11).

Numerous studies indicate that productivity in mining and mineral industries depends on multiple factors, including advanced technologies, human resource management, capital and resource management, production processes, and managerial and systemic capabilities. Therefore, productivity research can help identify challenges and opportunities for improving performance in the mining and mineral industries sector. According to statistical reports, Europe accounts for approximately 7% of global mineral extraction, with nearly €94.4 billion in gross domestic product generated from mining activities in several leading European countries (12). An analysis of models based on data from 45 medium- and large-sized mining companies from 2018 to 2022 revealed a clear relationship between economic performance and corporate social responsibility in mining companies. The findings confirm that corporate social responsibility has a positive effect on economic growth, including profitability and productivity. Moreover, human resources and community development were identified as the most influential indicators affecting economic growth in mining industries (13). In recent years, there has been increasing interest within mining and mineral industries policymaking communities in applying system dynamics modeling to address the complexity of policy-related issues. The aim of system dynamics is to support the analysis and resolution of complex problems by identifying key factors and their interrelationships to provide structured analytical frameworks (14).

No study was found that directly examined productivity in mining and mineral industries organizations using a system dynamics approach; however, several related studies have been conducted, the most important of which are reviewed below. The study by (15) on designing a dynamic balanced scorecard as an industrial safety management system in mining metallurgy concluded that key influencing factors included the dynamic balanced scorecard (with components of dynamic simulation for organizational learning and strategic improvement in safety performance measurement), soft systems methodology and systems thinking (with components related to solving complex human and organizational problems in mining environments and improving interdepartmental coordination and comprehensive decision-making), and industrial safety (with components such as accident prevention culture, reduction of accidents and downtime, increased employee motivation, leadership commitment to safety, and occupational diseases among mining personnel).

In a study on factors affecting capital productivity in the mining sector, (16) found that per capita capital, mineral price indices, energy consumption efficiency, and the share of private ownership significantly influenced capital productivity in mining. Accordingly, improving energy efficiency, reducing per capita capital, and increasing mineral prices lead to higher average capital productivity. In another study, (17) reported that the share of skilled workers, private ownership of mines, per capita capital, and wages had positive effects on labor productivity in mining. Therefore, improving labor productivity requires designing compensation and reward systems aligned with workers' value added, adopting labor-saving technologies (advanced mining equipment) in deep and high-risk mining operations, privatizing non-strategic mines, increasing labor participation in mineral sales and profits, and considering substitution and complementarity relationships among labor, energy, and capital in mineral extraction and processing.

Furthermore, (18) concluded that labor productivity decline in copper mining is influenced by four factors: real mining wages, electricity prices, copper prices, and ore grade. In another study, (19) examined energy prices, energy productivity, and capital productivity and reported that increases in energy prices, the energy-to-capital ratio, and the energy-to-output ratio affect capital productivity and may generate price shocks.

The primary motivation for conducting this research is to enhance productivity by addressing the social, economic, and political phenomena affecting the mining and mineral industries sector and to improve organizational performance, enabling organizations to adopt appropriate strategies in competitive environments when confronting industry-specific challenges. Mining and mineral industries, operating with diverse facilities and equipment and facing high resource costs, seek to optimize resource utilization to achieve organizational objectives and improve productivity. Accordingly, research on productivity in mining and mineral industries organizations is of particular importance and can effectively guide organizations toward success and sustainable development. Therefore, the main objective of this study is to comprehensively identify and analyze the factors affecting productivity in mining and mineral industries organizations, enabling decision-makers and policymakers to optimally utilize sectoral capacities and enhance productivity. In essence, this study seeks to simulate and analyze managerial scenarios for improving productivity in mining and mineral industries organizations. Based on the foregoing discussion, the present research aims to design an integrated simulation and managerial scenario analysis model for enhancing productivity in mining and mineral industries organizations using a system dynamics approach.

Methods and Materials

In terms of purpose, this study was applied, and in terms of implementation, it was descriptive. In addition, with respect to the nature of the research method, the study adopted a mixed (integrative) methodology.

First, a qualitative analysis was conducted on the data obtained from interviews with experts in the mining and mineral industries sector, as well as on the factors identified from the literature review presented in Chapter Two of the study. This phase employed the grounded theory approach using MAXQDA software. Data for this part of the research were collected through semi-structured interviews and expert elicitation with specialists in the mining sector, and the resulting interview data were systematically analyzed. At this stage, 12 main categories were extracted, which were further organized into 25 axial codes, 51 open codes, and 180 indicators.

In the second phase, fuzzy DEMATEL was used to analyze and examine the relationships among the criteria extracted from the qualitative data. The capabilities of fuzzy logic enable the precise identification of complex causal relationships among interrelated factors. The 12 main categories identified in the previous stage were presented to the research experts in the form of a pairwise comparison questionnaire, and the respondents were asked to complete it. This questionnaire consisted of a 12 × 12 matrix, and ultimately, by constructing the total relation matrix and summing the values of rows (D) and columns (R), key indices for each criterion were obtained. In the subsequent step, the findings related to model design were further examined and analyzed using another questionnaire, which was developed based on the model extracted in the previous stage. All collected data were statistically analyzed using SmartPLS software. In this section, measures of central tendency and dispersion for the questionnaire items were examined, and a total of 57 items were confirmed as observed variables based on central indices and dispersion measures. Using structural equation modeling, along with various statistical tests and factor loadings, model fit and validation were conducted.

In the final stage, Vensim PLE software and the system dynamics methodology were used to design an integrated model of the factors affecting productivity in mining and mineral industries organizations. Causal loop diagrams and stock-and-flow diagrams of the identified variables were developed, and the behavior of the model was simulated against the real behavior of the system over a 10-year time horizon. Various scenarios were then formulated to identify and analyze effective strategies for achieving the desired state and were made available to managers in this sector. It should be noted that, for data collection at this stage, the National Iranian Copper Industries Company was selected as one of the mines and subsidiary companies of IMIDRO. This company holds the highest rank and standing in the IMIDRO Productivity Excellence Award, and the required information was extracted from the official CODAL system.

The statistical population in the qualitative phase of the research included specialists, academics, managers, experts, and scholars in the mining and mineral industries sector who possessed substantial domain-specific knowledge. These participants were selected using purposive and criterion-based sampling. In accordance with the research methodology, 30 experts with sufficient expertise in this field were included as the qualitative sample until theoretical saturation was achieved. In this study, efforts were made to ensure that the panel of experts met three prerequisite criteria for selection: holding postgraduate degrees (master's or doctoral level) in management, mining engineering, or mineral industries and related fields; having at least 10 years of continuous professional experience in their respective fields; and possessing both practical and theoretical experience in the mining and mineral industries sector, in order to ensure the credibility and validity of the research findings.

In the quantitative phase related to fuzzy DEMATEL, a total of 40 participants took part in the study. In the quantitative phase of the structural equation modeling, the statistical population comprised practitioners in the mining and mineral industries sector, including experts, managers, and specialists at the Iran Mineral Processing Research Center and its parent organization (IMIDRO). The sample size was estimated at 174 individuals based on Cochran's formula, and participants were selected using stratified random sampling according to key subgroups (management, engineering, human resources, maintenance and repair, and safety and environment). In this sampling method, the size of each key subgroup within the population was calculated, and samples were drawn proportionally from each subgroup based on the total sample size.

For model simulation in this study, a 10-year time horizon was considered. This 10-year period was selected because it both captures a reliable historical trend and aligns with the strategic planning horizon of the National Iranian Copper Industries Company and the development programs of IMIDRO. In addition, changes in investment and technology in the mining and mineral industries typically demonstrate their effects over periods of 5 to 10 years. It should be noted that, for data collection at this stage, the National Iranian Copper Industries Company was selected as one of the mines and subsidiary companies of IMIDRO. This company holds the highest rank and award level in the IMIDRO Productivity and Excellence Award, and the required information was extracted from the official CODAL system as well as from the excellence and planning units of the company in accordance with the research questionnaires.

Findings and Results

Before analyzing the data using the system dynamics approach, it is necessary to briefly refer to the results of the previous qualitative and quantitative phases. First, using the grounded theory method and MAXQDA software, the research criteria were identified, resulting in 12 selective codes, 25 axial codes, 51 open codes, and 180 categorized indicators and concepts. Subsequently, using the fuzzy DEMATEL method and based on the sum of the elements of each row (D), it was determined that criterion C6 (leadership, management, and policymaking), criterion C11 (economic and financial performance), and criterion C1 (improvement of organizational structures and processes) had the highest levels of influence. In addition, based on the sum of the column elements (R), criterion C3 (technology and innovation), criterion C9 (management and operational productivity), and criterion C2 (technological infrastructure) exhibited the highest levels of dependence. Based on the vertical vector (D − R), the influence power of each factor was identified, such that criteria C6, C10, C5, C11, and C1, with positive values, were classified as causal variables, whereas criteria C4, C9, C12, C2, C8, C7, and C3, with negative values, were considered effect variables. Subsequently, using structural equation modeling, measures of central tendency (mean) and dispersion (standard deviation and variance) were calculated for the 57 confirmed items or questions. By conducting tests of data distribution and correlation, the symmetry and normality of the distributions and the relationships among the research variables were examined. After identifying the abbreviations of the observed and latent variables, the paradigm model diagram was designed and drawn using SmartPLS software. Then, through three main steps and by applying multiple methods, the fit and validation of the model were assessed. Specifically, factor loadings, Cronbach’s alpha, and convergent validity were used to evaluate measurement reliability and fit; Z coefficients, R^2, and Q^2 indices were used to assess the structural fit of the model; and the goodness-of-fit index was employed to evaluate the overall model fit.

Table 1. Role of Each Research Criterion Loop in the System Dynamics Model

Type of Loop in the System Dynamics Model	Research Criteria	Research Dimensions
Endogenous and positive feedback loop	Improvement of organizational structures and processes	Causal conditions
Endogenous and positive feedback loop	Technological infrastructure	
Endogenous and positive feedback loop	Technology and innovation	
Endogenous and positive feedback loop	Human resource empowerment	Contextual conditions
Exogenous	Economic factors and macro-level policymaking	
Exogenous	Leadership, management, and policymaking	Intervening conditions
Endogenous and positive feedback loop	Organizational risk and safety management	
Endogenous and positive feedback loop	Supply chain and resources	
Endogenous and positive feedback loop	Management and operational productivity	Strategies
Exogenous	Human capital development	
Exogenous	Economic and financial performance	Outcomes
Endogenous and positive feedback loop	Sustainability and social responsibility	
Negative feedback loop	Mineral resource capacity	

Using the formed loops, the overall causal loop diagram was developed in accordance with Figure 1. In system dynamics, causal loop diagrams depict the core architecture of a system along with the manner in which causes influence effects, and they are considered efficient tools for representing the feedback structure of systems. These diagrams are used to illustrate the conceptual relationships among variables, their mutual influences, and the structure of feedback loops. In other words, they function as tools for mapping causal relationships among a set of variables within a system, in which the arrows indicate the path and direction of influence of one variable on another.

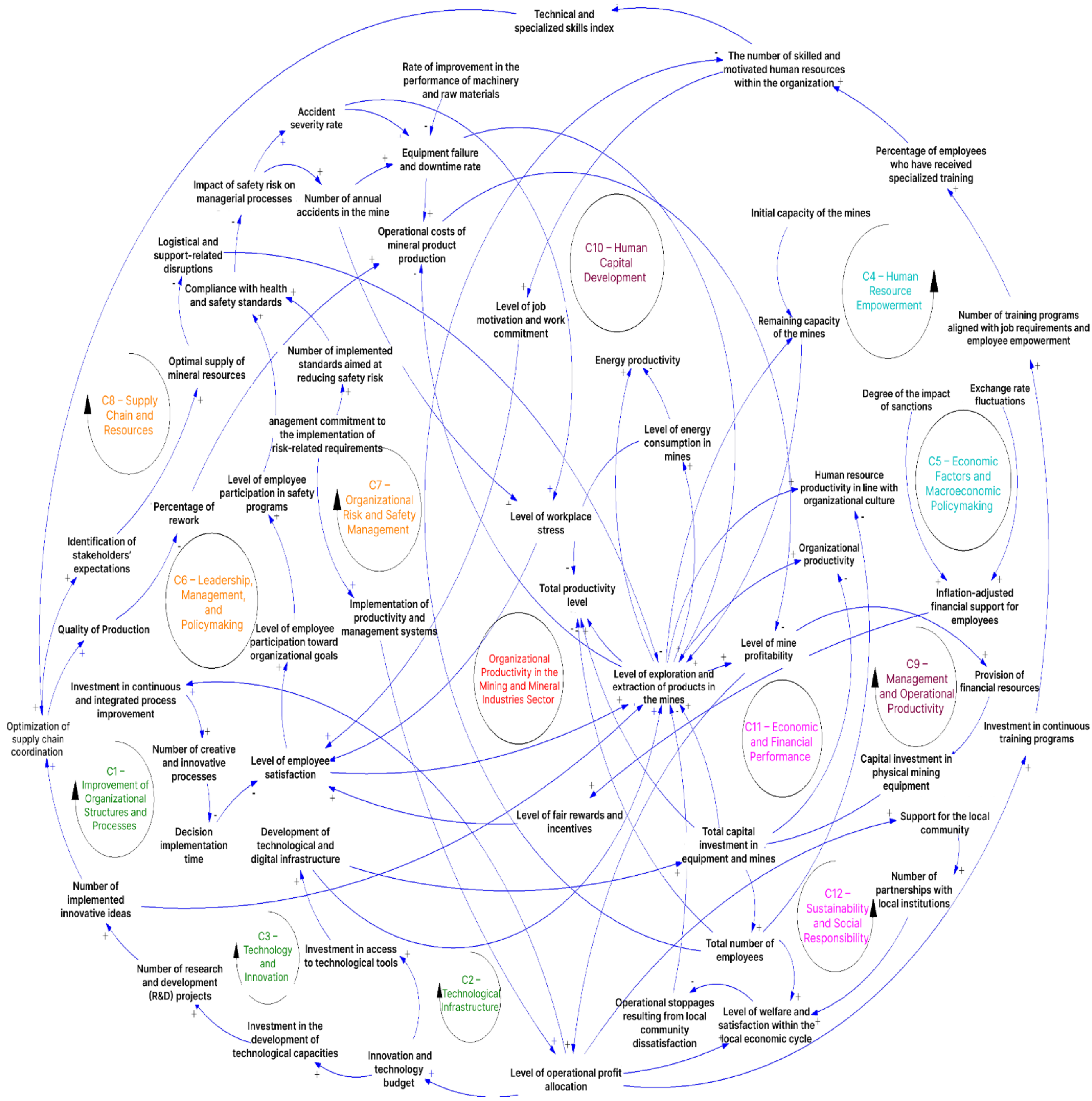


Figure 1. Results of the Causal Relationships of Factors Affecting the Enhancement of Productivity in Mining and Mineral Industries Organizations

Based on the causal relationships of the factors affecting the enhancement of productivity in mining and mineral industries organizations reported in Figure 1, a stock-and-flow diagram was designed, which transforms these causal relationships into relationships that can be simulated. The stock-and-flow diagram is one of the main tools in the system dynamics approach, through which the structure of a system is transparently and comprehensibly represented, and the relationships between auxiliary and core variables are specified via stocks (accumulations) and rates (flows), enabling the examination of causal relationships and feedback mechanisms within the system. Accordingly, the results of the simulation relationships for the factors affecting the enhancement of productivity in mining and mineral industries organizations through stocks and flows are reported in Figure 2.

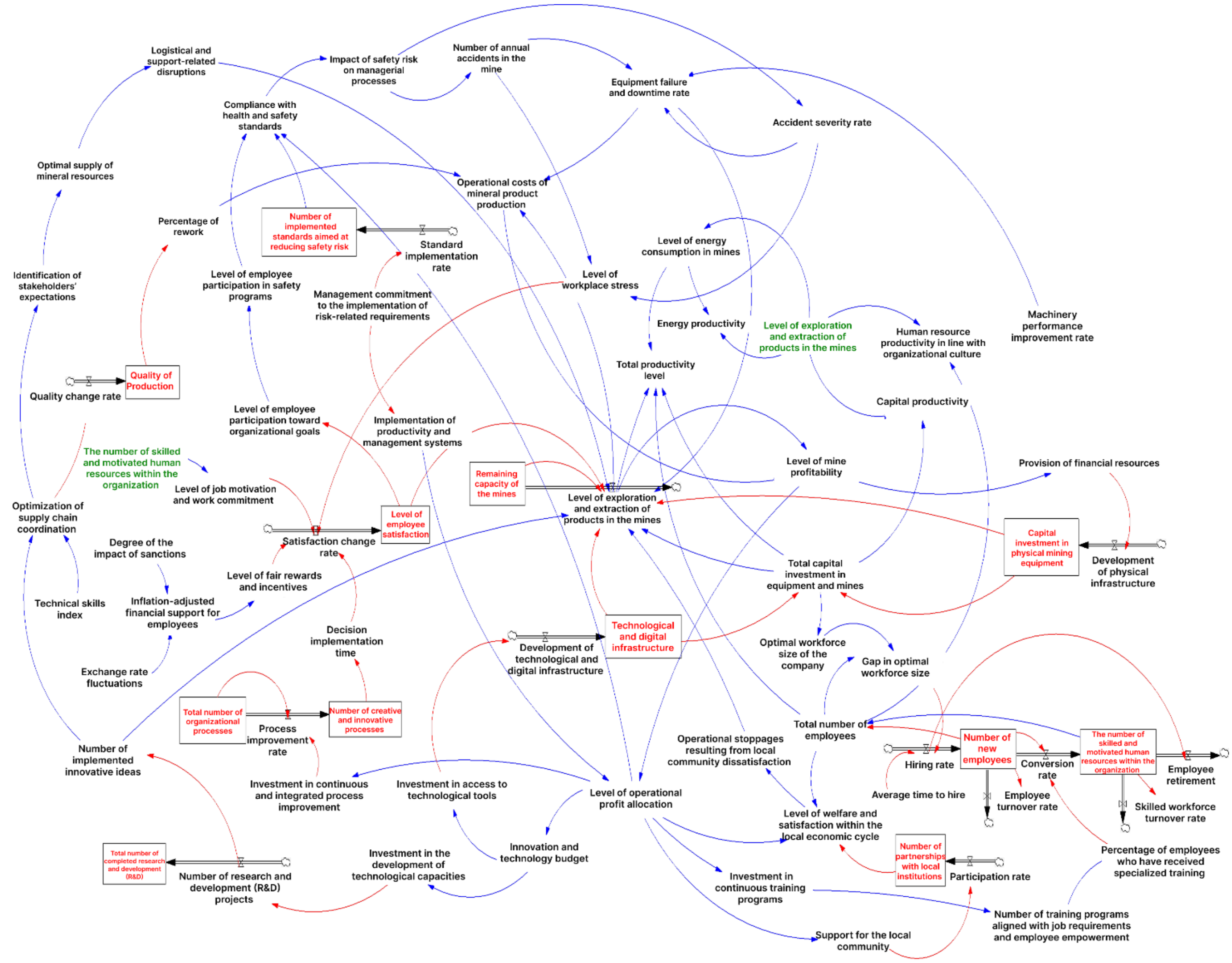


Figure 2. Results of Simulation Relationships for the Factors Affecting the Enhancement of Productivity in Mining and Mineral Industries Organizations through Stocks and Flows

The simulation results through stocks and flows reported in Figure 2 indicate the quantitative and dynamic structure of the system, which converts the identified causal relationships into relationships suitable for simulation. In this study, a 10-year time horizon was considered for model simulation. This period was selected because, on the one hand, it captures a reliable historical trend, and on the other hand, it is consistent with the strategic planning horizon of the development programs of the National Iranian Copper Industries Company and IMIDRO. In addition, changes in investment and technology in the mining and mineral industries typically demonstrate their effects over periods of 5 to 10 years.

After developing the stock-and-flow diagram of the study, it was necessary to define the mathematical relationships among the variables. The model equations were formulated using one of the productivity measurement models, namely Total Factor Productivity (TFP), to define productivity index formulas. In this approach, various factors such as labor, capital, technology, and energy are considered. The formula is expressed as TFP = Y / A(L, K), where Y denotes output, L represents labor, K denotes capital, and A is a function of labor and capital. Quantitative productivity models based on the system dynamics approach are effective tools for achieving a deeper understanding of complex systems. Accordingly, mathematical formulas and nonlinear functions suitable for simulation were developed. Furthermore, to enable the creation and computation of all criteria, equations, formulas, and interrelationships within the software, the path coefficient shares for each research criterion obtained from the structural equation modeling were incorporated into Vensim as weights for the variables, adopting a data-driven approach.

Nearly 50 formulas were used in this study within the Vensim software. The most important formulas applied are as follows:

Total Factor Productivity: the main basis for calculating productivity indices and overall system productivity over time.

Human Resource Productivity = Mining Output / Total Workforce

Capital Productivity = Mining Output / Total Equipment and Technology Capital

Energy Productivity = Mining Output / Energy Consumption in Mines

Total Factor Productivity = Income / (Energy Consumption in Mines × Price of Energy + Total Equipment and Technology Capital + Total Workforce × Cost of Human Resources)

Total number of safety action plans

Total Safety Action Plan Count = ∫ Safety Action Plan Rate · dt + 55

Number of skilled and committed employees

Skilled and Committed Employees = ∫ (Conversion Rate − Retirement Skilled Employee Exit Rate) · dt + 4,890

Hiring rate

Hiring Rate = Workforce Gap / Average Time to Hire

Mining output based on the 12 research criteria and structural equation modeling path coefficients

Mining Output = $\Sigma_{i=1}^{12} W_i \times C_i$

Product quality: one of the main inputs to the technology development loop

Product Quality = ∫ Quality Change Rate · dt + 0.9

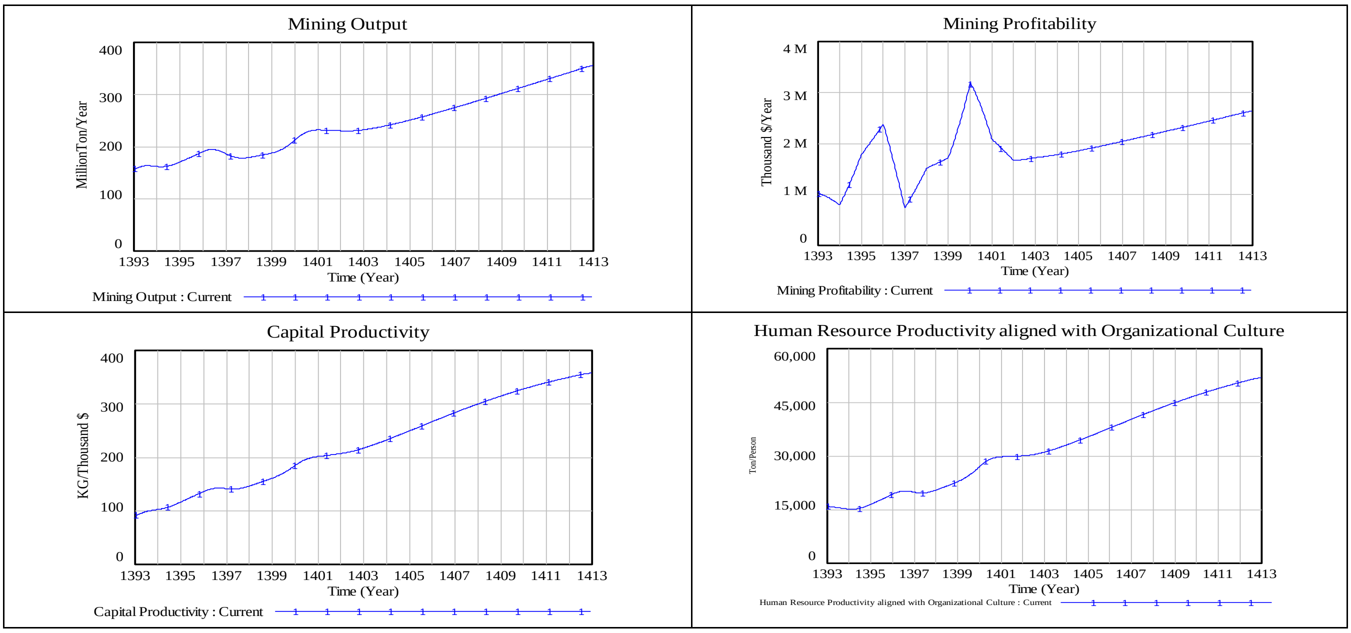
To simulate the model in this study, a 10-year time horizon was considered. This 10-year period was selected because, on the one hand, it captures a reliable historical trend and, on the other hand, aligns with the strategic planning horizon of the National Iranian Copper Industries Company and the development programs of IMIDRO. The National Iranian Copper Industries Company is one of the largest and most strategic companies in the country's mining and non-ferrous metals industry, operating in the fields of exploration, extraction, processing, and final copper product production. As a core component of Iran's copper mining value chain, this company plays a pivotal role in value creation, employment generation, and foreign exchange earnings in the mining sector. By operating major mines such as Sarcheshmeh, Sungun, and Miduk, the company has a central role in value added, exports, and foreign currency generation for the country. Accordingly, analyzing its productivity yields applied results that are generalizable to other IMIDRO-affiliated organizations. In terms of mission and scope of activity, the National Iranian Copper Industries Company focuses its operations on three main areas: exploration and extraction, copper ore processing and concentrate production, and value chain development and investment in downstream industries. Overall, the selection of the National Iranian Copper Industries Company as the case study, due to the scale of its operations, access to reliable data, the presence of productivity challenges, and the implementation of improvement programs, provides an appropriate context for system dynamics model simulation and policy scenario analysis.

It should be noted that prior to analyzing managerial scenarios for enhancing productivity in mining and mineral industries organizations, the validity of the model was examined using various methods, including extreme condition tests, structural and behavioral validation tests, and reference mode behavior tests. In the extreme condition test, the model's input variables were examined under different values, and the analysis of model behavior demonstrated that the model exhibited logical behavior under extreme conditions, with no unreasonable behavior observed as a result of these or other changes in input variables. In the structural and behavioral validation test, the structure of the model was evaluated in terms of the correctness of the assumed relationships and linkages, and in this study, the structure and behavior of all variables were confirmed. In the reference mode behavior test, the level of mineral extraction generated by the model was compared with its historical data pattern, and the results indicated that the model was able to satisfactorily reproduce variable behavior relative to historical data. In addition, four other tests—parameter assessment, integral error test, sensitivity analysis test, and boundary adequacy test—also indicated the acceptable validity of the model.

After conducting simulation and validation of the productivity enhancement model for mining and mineral industries organizations using a system dynamics approach, the analysis of policy scenarios aimed at evaluating system behavior under different managerial and decision-making conditions is presented. Scenario analysis allows the researcher to examine the effects of changes in key parameters over a future time horizon; in the present study, a 10-year horizon covering the period from 2024 to 2034 was examined. It should be noted that scenario analysis helps identify policies that have the greatest impact on productivity improvement and can be utilized in managerial and policymaking decisions.

Scenario 1: Continuation of Current Conditions or Maintenance of the Status Quo

In this scenario, the values of the main model parameters were set based on the existing conditions, and no new policies were introduced. The results of the managerial scenario analysis for the continuation of current conditions or maintenance of the status quo in enhancing productivity in mining and mineral industries organizations are reported in Figure 3.



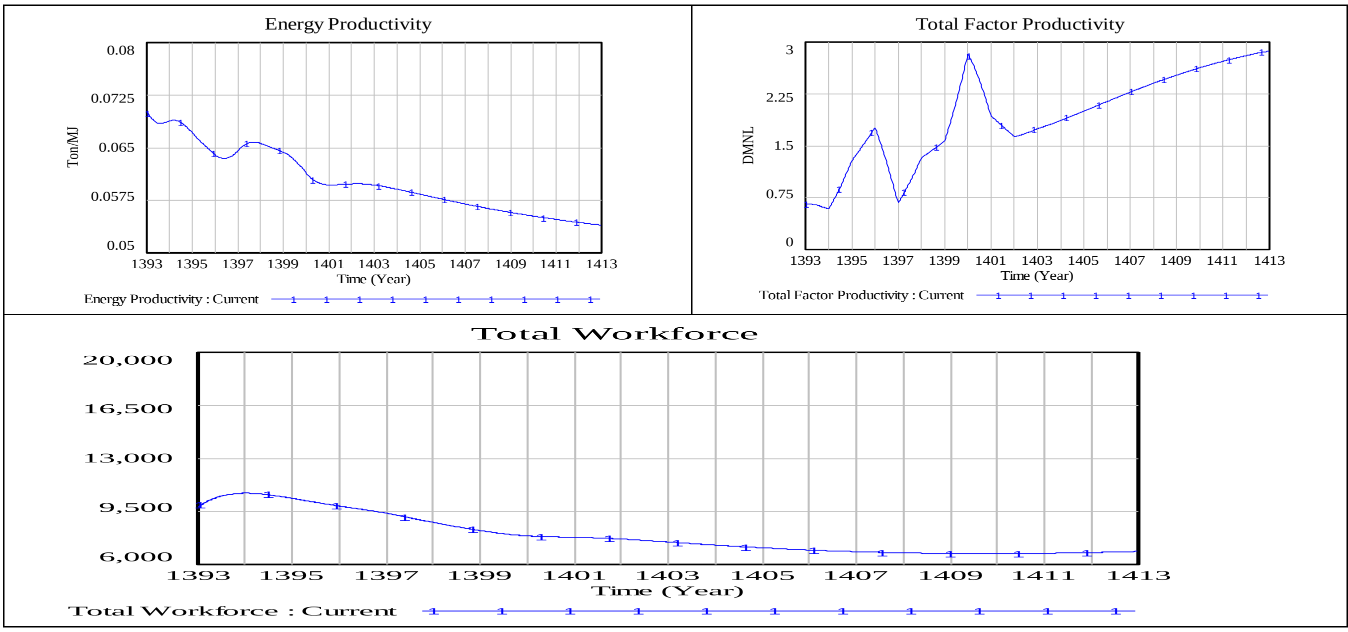


Figure 3. Results of the Managerial Scenario Analysis for the Continuation of Current Conditions or Maintenance of the Status Quo in Enhancing Productivity in Mining and Mineral Industries Organizations

The results of the first or baseline managerial scenario analysis reported in Figure 3 indicate that the system, under current conditions, possesses internal dynamics and a natural growth capability; however, some indicators exhibit different behaviors, reflecting the presence of both opportunities and structural challenges within the productivity system. The mineral extraction curve shows an upward and stable trend, and this growth is the result of past capacity development, increased operational experience, and the stabilization of production cycles. Capital productivity and labor productivity also display upward trends, with the increase in capital productivity mainly attributable to more effective use of equipment and the gradual expansion of operational capacity. Labor productivity improves as the number of employees decreases relative to production levels. In contrast, energy productivity follows a downward trend, indicating that energy consumption is increasing at a faster rate than production. This represents one of the most critical challenges under current conditions and may lead to increased production costs in the long term. Total factor productivity also experiences a mild upward trend, reflecting the combined effects of improvements in capital and labor. The total workforce shows a declining slope, which is consistent with the structure of Iran's mining industry, characterized by heavy equipment usage and gradual automation. Overall, the analysis of the first or baseline scenario indicates that if current conditions persist, the organization will experience sustainable growth in production, profitability, and some productivity indicators over the 10-year horizon; however, the challenge of energy productivity and dependence on energy resources will remain and may become a structural weakness in the future. These results highlight the necessity of examining policy scenarios and managerial interventions to improve total productivity and achieve more sustainable growth.

Scenario 2: Development of Technological Infrastructure or an Infrastructural Technological Leap

This scenario examines the effects of a 55% increase in technological infrastructure over the period from 2024 to 2034 on various dimensions of productivity and the economic performance of the system. Compared with the continuation of current conditions, this increase results in an additional 7% improvement. The results of the managerial scenario analysis for the development of technological infrastructure or an infrastructural technological leap in enhancing productivity in mining and mineral industries organizations are reported in Figure 4.

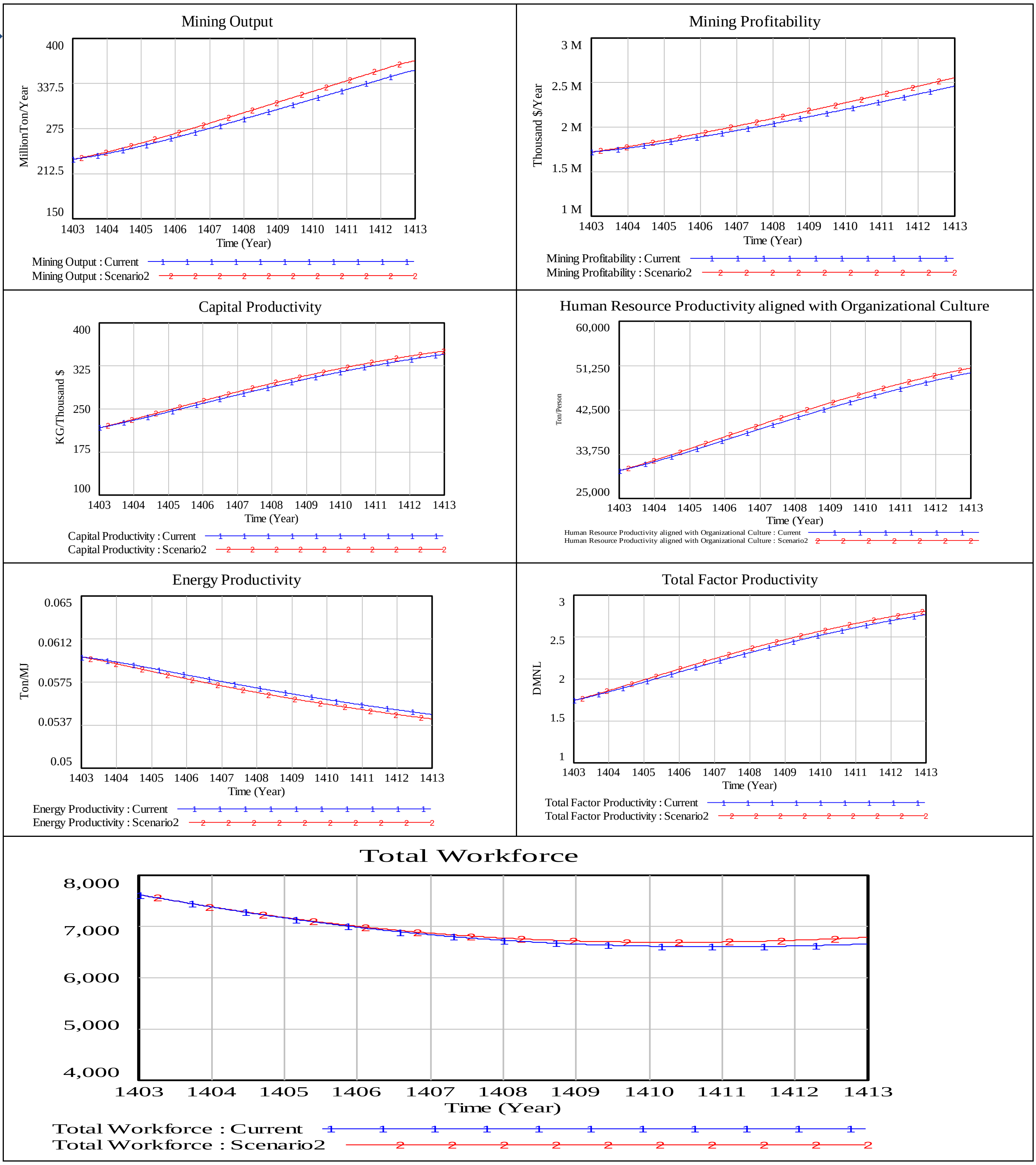
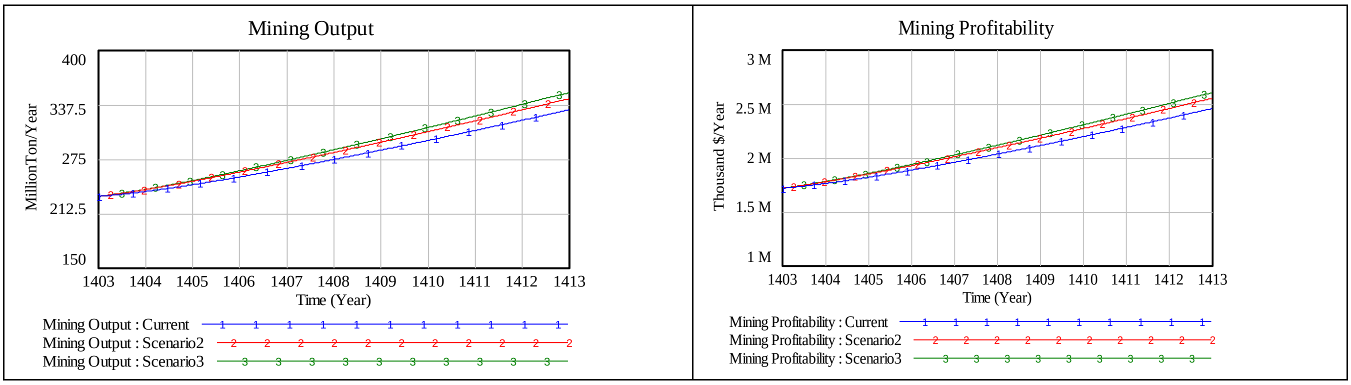


Figure 4. Results of the Managerial Scenario Analysis for the Development of Technological Infrastructure or an Infrastructural Technological Leap in Enhancing Productivity in Mining and Mineral Industries Organizations

The results of the second managerial scenario analysis reported in Figure 4 indicate that mineral extraction experiences an upward and stable trend, moving from values lower than those of the baseline scenario in 2024 to higher values in 2034. This finding suggests that the introduction of new technologies, through reduced downtime, increased operational precision, and improved process management, has enhanced the operational capacity of the system. Company profitability also shows a significant increase during this period, rising from approximately USD 1.5 million to more than USD 2.5 million. This growth in profitability is attributable to reductions in direct costs, improved data-driven decision-making, and increased efficiency of production operations. Both capital productivity and labor productivity improve relative to the baseline scenario. The increase in capital productivity reflects more optimal use of equipment, improved return on investment, and reduced fixed investment costs. Labor productivity also follows an upward trend as a result of training and improved operational coordination, indicating enhanced employee skills and efficiency. In contrast, energy productivity in this scenario shows a greater decline compared to the baseline condition; however, this decline is milder and more controlled, and the trend remains relatively downward. The behavior of total factor productivity and workforce size indicates that total productivity increases at a steeper rate than in the baseline scenario, experiences an initial decline, but stabilizes toward the end of the period and remains slightly higher than in the baseline managerial scenario. This suggests that the introduction of technology has replaced part of human activities, increased automation, and improved system performance without relying on workforce expansion. Overall, the second scenario demonstrates that increasing technological infrastructure has positive and significant effects on production, profitability, and capital and labor productivity, leading to sustainable growth in output and profitability. However, to achieve balanced and sustainable growth and fully enhance energy efficiency and total productivity, complementary policies in the energy domain, along with structural and organizational reforms, need to be implemented alongside technological development. This scenario clearly emphasizes that technology is a primary driver of growth, but by itself is not sufficient to improve all productivity indicators.

Scenario 3: Increasing Investment in Physical Equipment Alongside Expansion of Technological Infrastructure Capital (Hardware and Technological Modernization)

This scenario examines the combined effect of increasing investment in physical equipment together with the development of technological infrastructure, which alters system behavior noticeably compared with the previous two scenarios. In this scenario, the depreciation trend of physical equipment is halted, and over the period from 2024 to 2034, an improvement of approximately 10% is achieved. This action, combined with digital development, increases the operational capacity of the mine, and its effects are observable across most performance variables. Accordingly, the results of the managerial scenario analysis of increasing investment in physical equipment along with expanding technological infrastructure capital, or hardware and technological modernization, for enhancing productivity in mining and mineral industries organizations are reported in Figure 5.



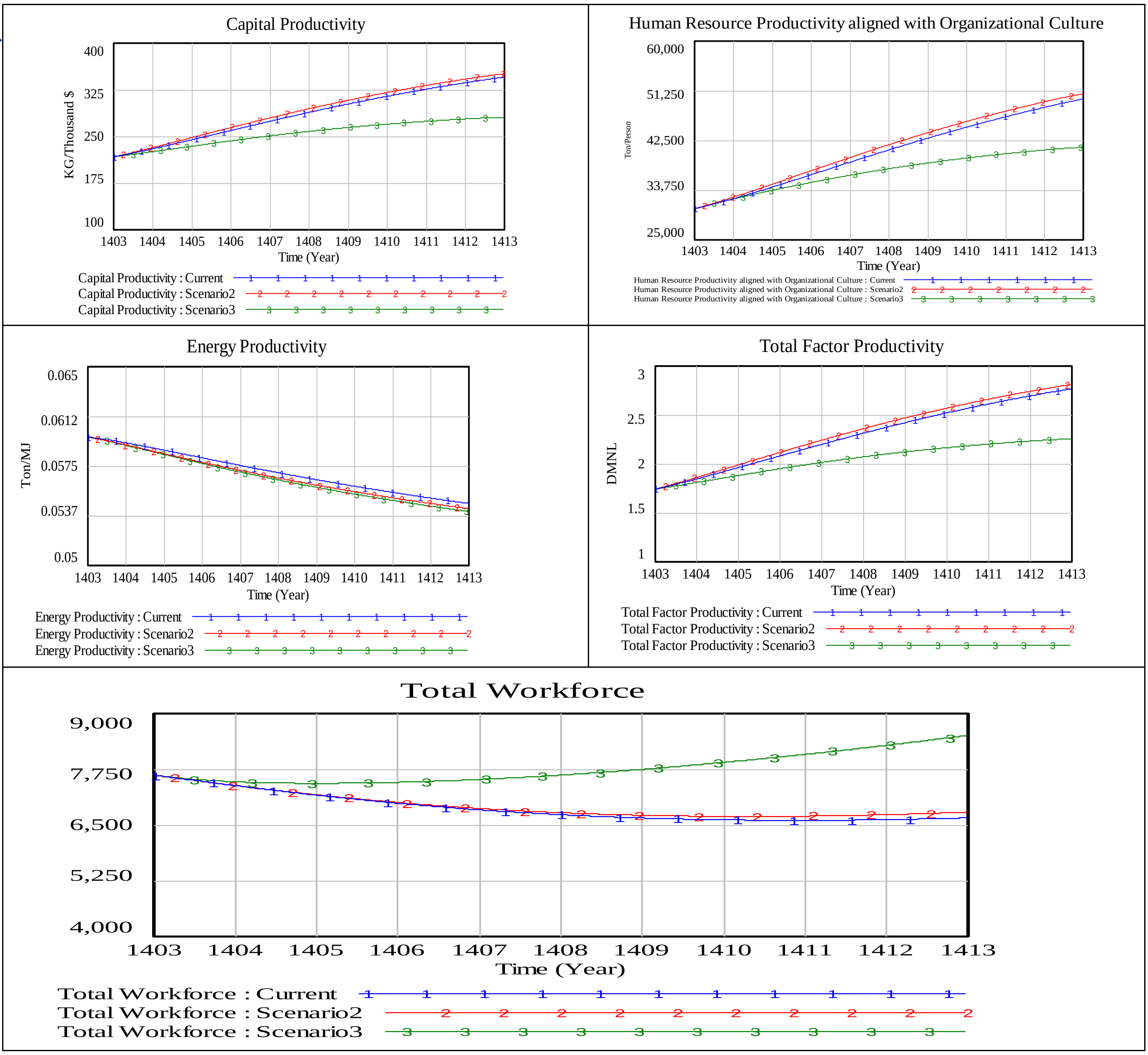
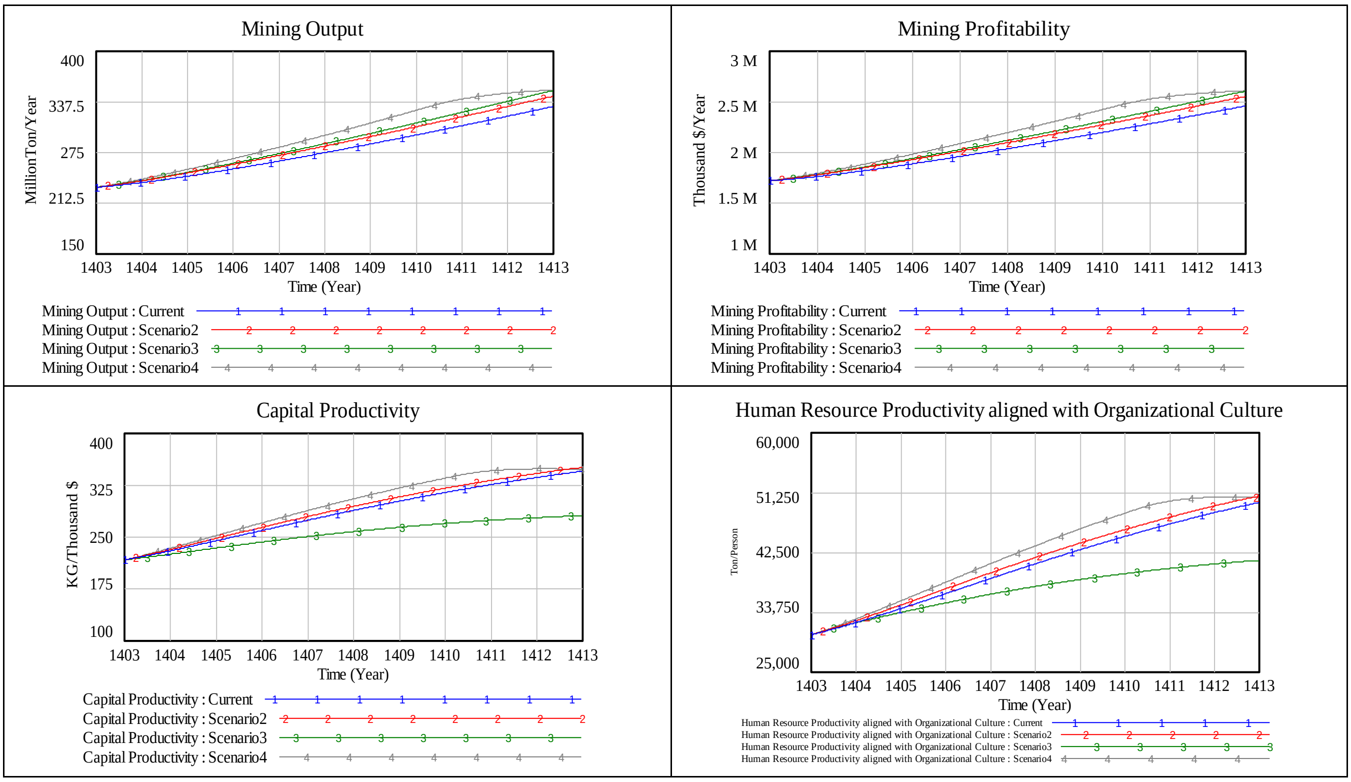


Figure 5. Results of the Managerial Scenario Analysis of Increasing Investment in Physical Equipment Alongside Expansion of Technological Infrastructure Capital (Hardware and Technological Modernization) for Enhancing Productivity in Mining and Mineral Industries Organizations

The results of the third managerial scenario analysis reported in Figure 5 indicate that mineral extraction experiences greater growth than in Scenario 2 and increases with a steeper slope. Equipment modernization, the reduction of breakdown-related downtime, and improvements in operational efficiency strengthen production capacity, leading to a noticeable increase in mineral extraction compared with the second managerial scenario. Mine profitability also increases significantly relative to Scenario 2, following an upward trajectory and reaching a higher level in the final years of the period. This increase is attributable to reduced maintenance costs, greater utilization of new machinery, and improved capital returns. In addition, capital productivity exhibits a substantial increase in this scenario, as new physical investment enhances the efficiency of machinery utilization and capital deployment. In contrast, labor productivity declines relative to Scenario 2. This outcome arises because increased physical capital investment, without simultaneous changes in organizational structures, skill development, and appropriate workforce allocation, leads to a disproportionate growth of labor relative to capital. Moreover, energy productivity declines with a steeper downward slope than in the previous scenarios. Although new equipment increases production, it is energy-intensive, and in the absence of reforms in organizational behavior and energy management, it results in reduced efficiency of energy consumption. Furthermore, the growth trend of total factor productivity slows and stabilizes at a level lower than that observed in Scenario 2. In this scenario, the total workforce increases, contrary to the trends observed in the previous two scenarios, which itself constitutes one of the factors contributing to the reduction in total productivity. Overall, Scenario 3 demonstrates that investment solely in physical equipment, although leading to significant improvements in production and capital productivity, will result in a decline in total productivity and an intensification of energy inefficiency if not accompanied by organizational reforms, workforce skill enhancement, and energy management policies. Therefore, Scenario 3 performs positively only in the economic dimension and requires complementary policies from a productivity perspective.

Scenario 4: Simultaneous Improvement of Organizational Processes and Structures Alongside the Development of Technological Infrastructure (Structural and Digital Transformation of the Organization)

In addition to a 55% increase in technological infrastructure, this scenario also emphasizes organizational and process reforms. Compared with previous scenarios, each of which focused on a single investment dimension, this scenario adopts a multidimensional or integrated approach. This policy combination exhibits the highest degree of alignment with the nature of dynamic systems and generates the greatest efficiency across the entire system. In this scenario, it is assumed that investment in organizational processes and structures, alongside a 55% increase in technological infrastructure, leads to substantial improvements in organizational processes and structures. Accordingly, the results of the managerial scenario analysis of the simultaneous improvement of organizational processes and structures alongside the development of technological infrastructure, or the structural and digital transformation of the organization, for enhancing productivity in mining and mineral industries organizations are reported in Figure 6.



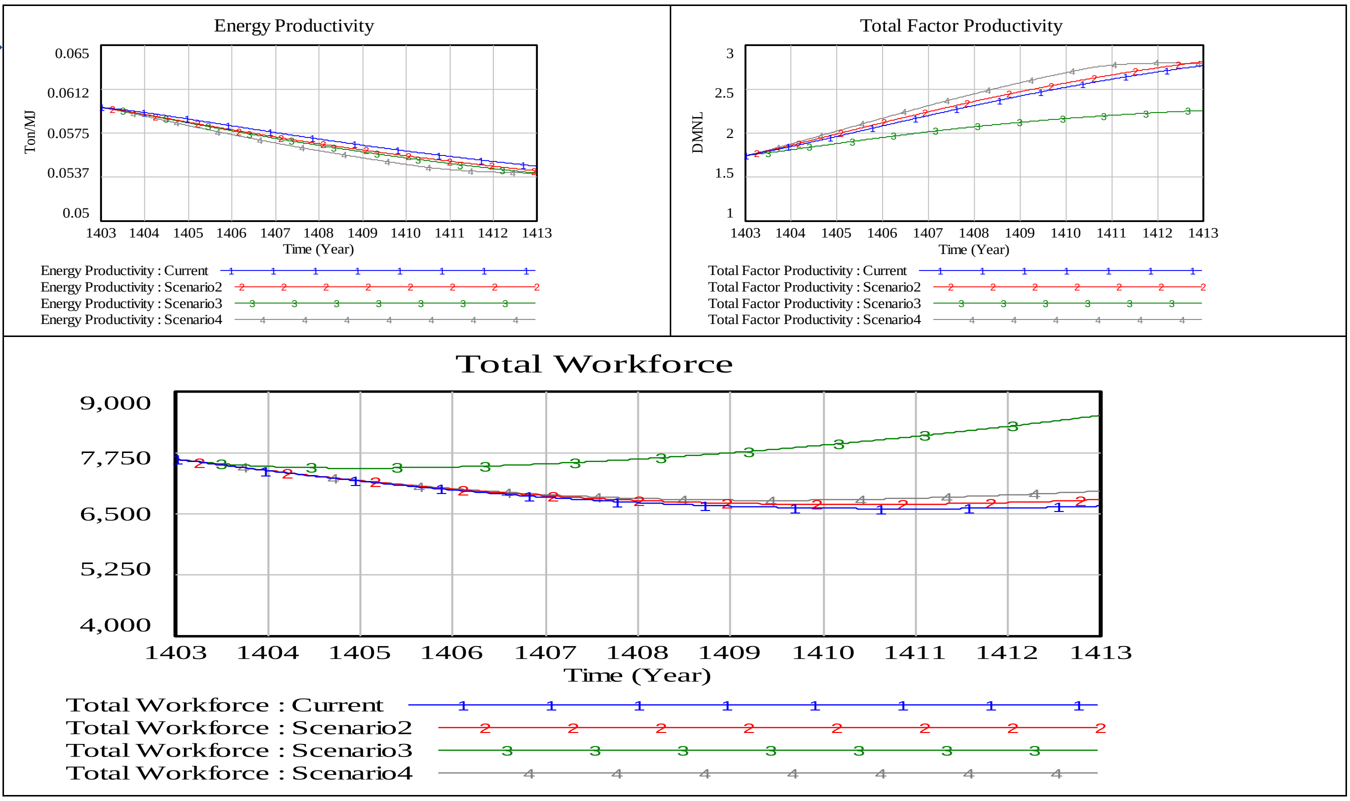
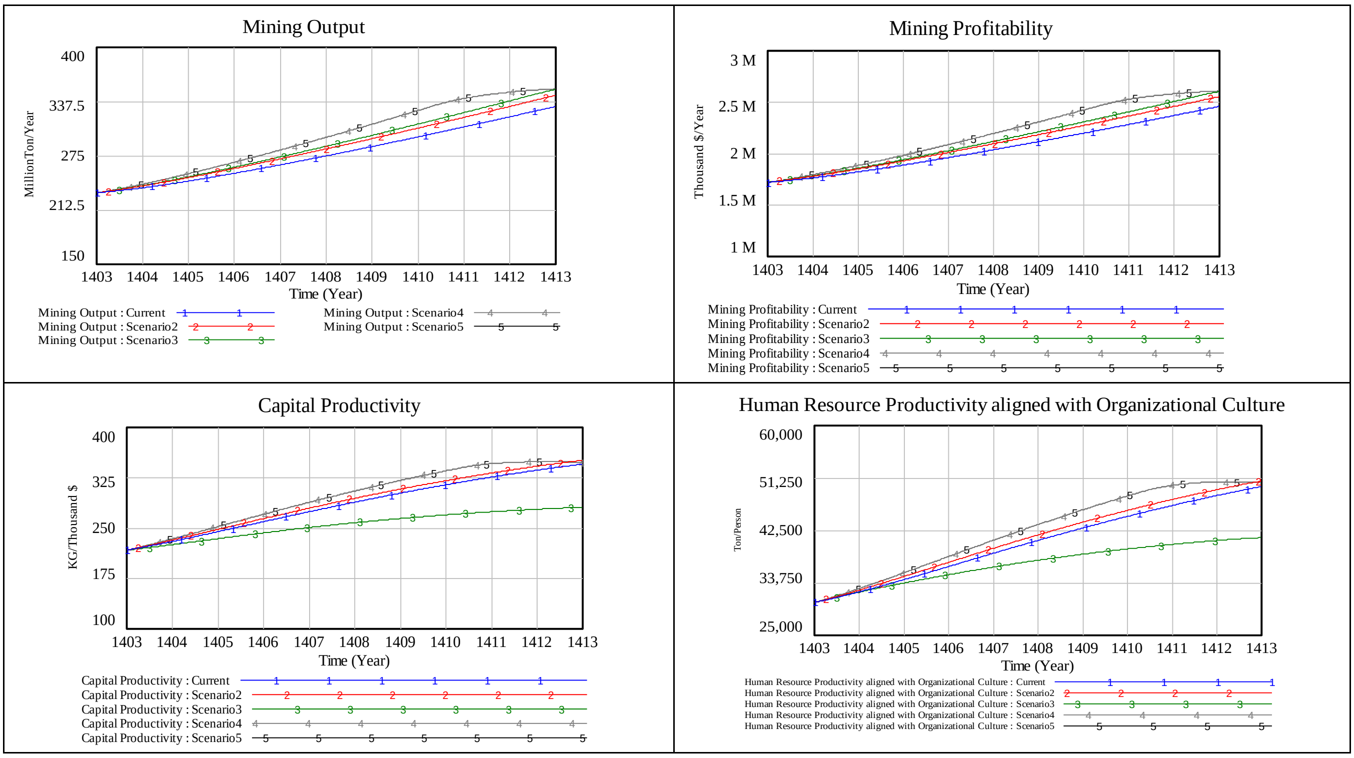


Figure 6. Results of the Managerial Scenario Analysis of the Simultaneous Improvement of Organizational Processes and Structures Alongside the Development of Technological Infrastructure (Structural and Digital Transformation of the Organization) for Enhancing Productivity in Mining and Mineral Industries Organizations

The results of the fourth managerial scenario analysis reported in Figure 6 indicate that this policy combination exerts the strongest positive effect on overall system performance. Under this scenario, mineral extraction reaches its highest level and the greatest magnitude among the four scenarios, with fully stable and upward growth throughout the period. This increase stems from enhanced operational coordination, reduced unnecessary downtime, and improved communication among different production units. Consequently, mine profitability also attains a higher level than in previous scenarios and increases substantially. The increase in profitability results from reduced rework, lower costs arising from inefficiencies, and more effective utilization of existing capacity, reflecting the synergistic effects of improved managerial structures, the application of new technologies, and the reduction of redundant activities in the production process. Capital productivity also follows an upward trend and exceeds that of all previous scenarios. Process improvements enable existing capital to be utilized more efficiently, minimizing time losses and equipment inefficiencies. Furthermore, labor productivity in this scenario increases with a steeper slope compared with earlier scenarios. In practice, organizational restructuring and facilitated information flows enhance employee efficiency and improve both individual and group performance. Nevertheless, energy productivity continues to exhibit a downward trend. Although the rate of decline is milder than in previous scenarios, it still indicates that managerial reforms alone are insufficient to fully control energy consumption, highlighting the need for complementary energy optimization policies. The behaviors of total factor productivity and workforce size indicate that the former follows an increasing trend, while the latter shows a mild upward trend. After an initial period of decline, the total workforce enters a phase of gradual increase, suggesting that despite process improvements and productivity gains arising from technology and structural reforms, increased activity volume and expanded production capacity create a long-term demand for additional labor. However, the workforce level in this scenario remains lower than in Scenario 3, indicating that organizational reforms and process improvements have partially offset the need for additional labor through efficiency gains. Overall, Scenario 4 demonstrates that combining the development of technological infrastructure with deep organizational reforms constitutes the most effective strategy for enhancing productivity and overall system performance. Unlike Scenario 3, in which physical development alone failed to improve total productivity, Scenario 4 highlights the critical role of managerial and structural coordination and the integration of technological development with structural and managerial reforms in achieving sustainable productivity. This integrated approach represents the most effective pathway for enhancing total productivity and ensuring long-term system sustainability, resulting in the highest levels of economic and operational performance of the mine relative to the previous scenarios.

Scenario 5: Implementation of Intelligent Energy Consumption Control Systems Concurrently with the Development of Technological Infrastructure (Smart Energy Optimization)

In this scenario, through the development of technological infrastructure and the deployment of intelligent energy control systems, energy consumption per unit of output is reduced by approximately 5%. Unlike previous structural scenarios, this policy focuses on improving energy efficiency and does not directly affect production processes or the workforce structure. Accordingly, the results of the managerial scenario analysis of implementing intelligent energy consumption control systems concurrently with the development of technological infrastructure, or smart energy optimization, for enhancing productivity in mining and mineral industries organizations are reported in Figure 7.



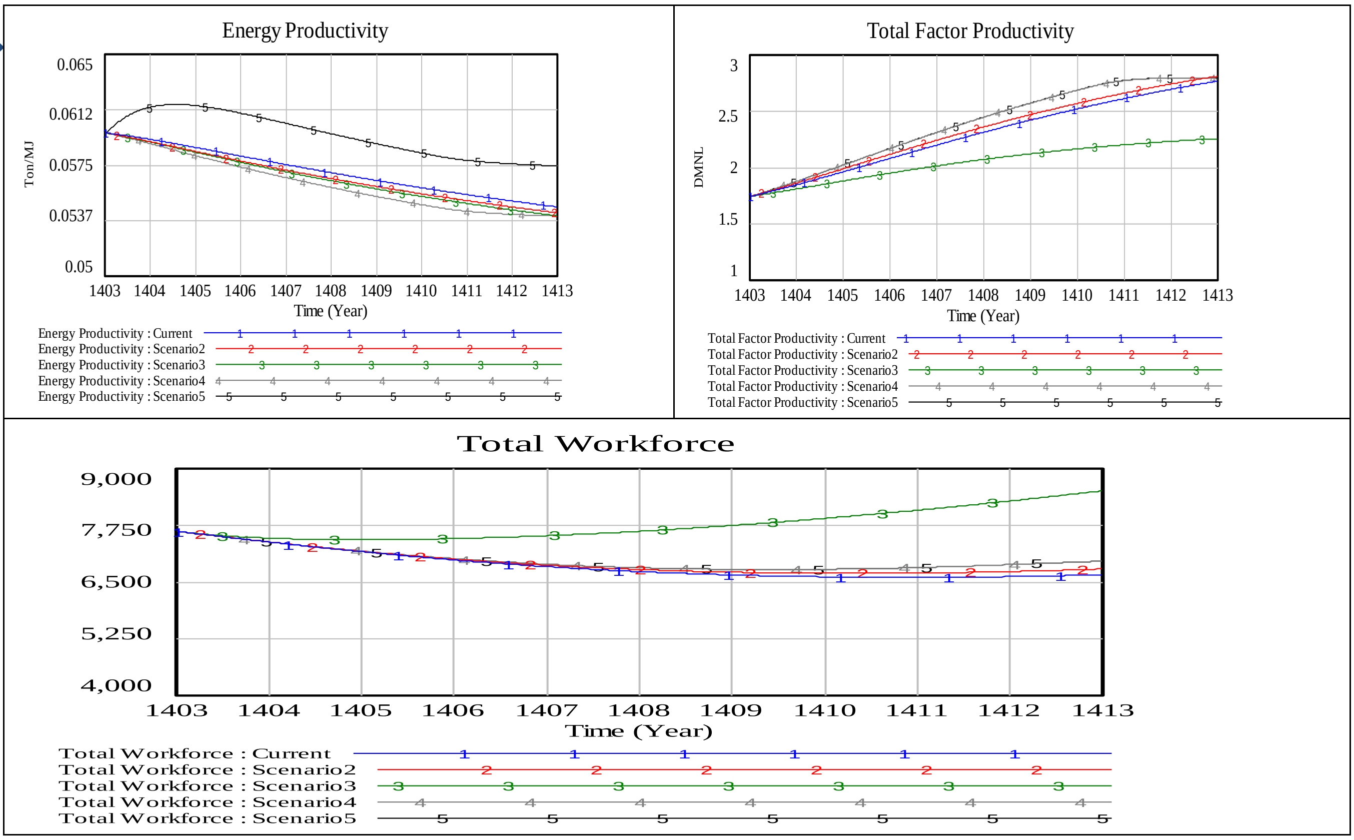
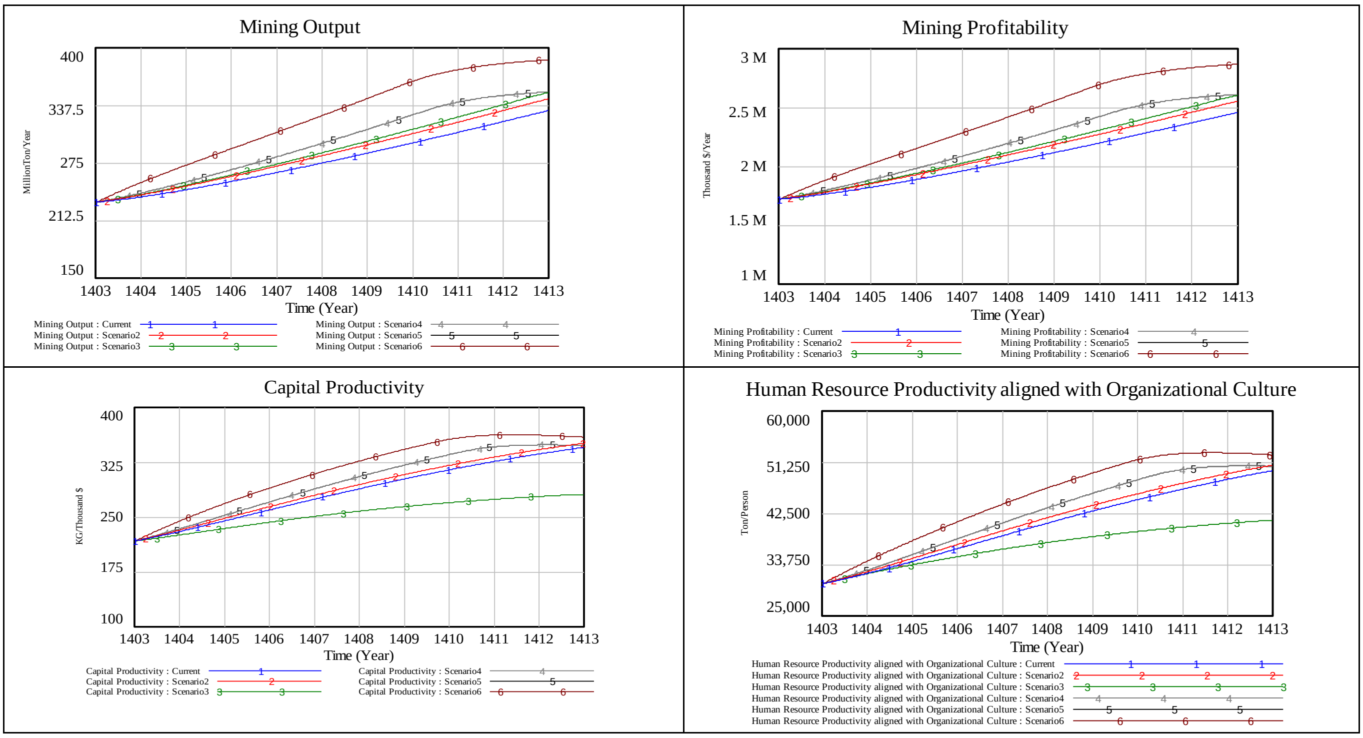


Figure 7. Results of the Managerial Scenario Analysis of Implementing Intelligent Energy Consumption Control Systems Concurrently with the Development of Technological Infrastructure (Smart Energy Optimization) for Enhancing Productivity in Mining and Mineral Industries Organizations

The results of the fifth managerial scenario analysis reported in Figure 7 indicate that mine output follows an upward, stable, and acceptable trend and performs better than the baseline and second scenarios. However, the difference relative to the third scenario is limited, and performance remains below that of the fourth scenario. This outcome is attributable to the fact that this scenario focuses on correcting energy consumption, while deep organizational reforms or extensive equipment modernization—central to Scenario 4—are not implemented. Mine profitability also exhibits an increasing trend, but this increase is primarily driven by gradual production growth and limited energy cost savings. Given that the share of energy costs in the mine's total cost structure is relatively lower than that of other factors, energy consumption reduction alone cannot generate a substantial increase in profitability. Consequently, the profitability level in this scenario remains lower than in more advanced scenarios, particularly Scenario 4. Capital productivity experiences a relative improvement, as reduced energy pressure on equipment and more stable operational performance allow machinery to operate with lower depreciation and higher efficiency. Nevertheless, the magnitude of this improvement is limited and does not reach the levels observed in scenarios involving structural reforms. The most pronounced positive effect of this scenario is observed in the energy productivity index, which attains the highest level compared with all previous scenarios. The use of intelligent monitoring and control systems enables the identification of energy losses, automatic shutdown of non-essential equipment, and optimization of consumption patterns, resulting in a significant reduction in energy consumption per unit of output. Labor productivity and total factor productivity also exhibit increasing trends, but these increases are more limited than those observed in scenarios involving organizational reforms. As no changes are implemented in managerial structures, incentive systems, or workforce skill development in this scenario, improvements in these indices are mainly attributable to gradual production growth rather than qualitative transformations in workforce performance. The total workforce remains nearly constant in this scenario, showing no significant fluctuations. Intelligent energy control systems play a supportive role and do not lead to labor substitution or substantial changes in employment structure. Overall, Scenario 5 demonstrates that the implementation of intelligent energy management systems is a highly effective policy for improving energy efficiency and reducing environmental impacts. However, due to its limited scope of influence, it is not sufficient on its own to generate a fundamental transformation in total productivity and mine profitability. This scenario can achieve maximum effectiveness only when implemented alongside organizational reforms, human capital development, and physical equipment modernization.

Scenario 6: Concurrent Development of Research and Development Projects, Reduction of Work-Related Stress, and Increased Investment in the Technical and Educational Skills of the Workforce (Knowledge-Based Strategic Maturity)

This scenario is considered the most comprehensive, as it incorporates, in addition to the interventions of Scenario 5, three additional key measures. These include a 40% increase in investment in research and development projects, a substantial reduction in workplace stress, and a 40% increase in investment in the development of the workforce's technical skills. This policy combination exerts a synergistic and highly powerful effect on most performance indicators, leading to the highest level of improvement in output variables such as mineral extraction, profitability, and labor and capital productivity. Accordingly, the results of the managerial scenario analysis of the concurrent development of research and development projects, reduction of work-related stress, and increased investment in the technical and educational skills of the workforce, or knowledge-based strategic maturity, for enhancing productivity in mining and mineral industries organizations are reported in Figure 8.



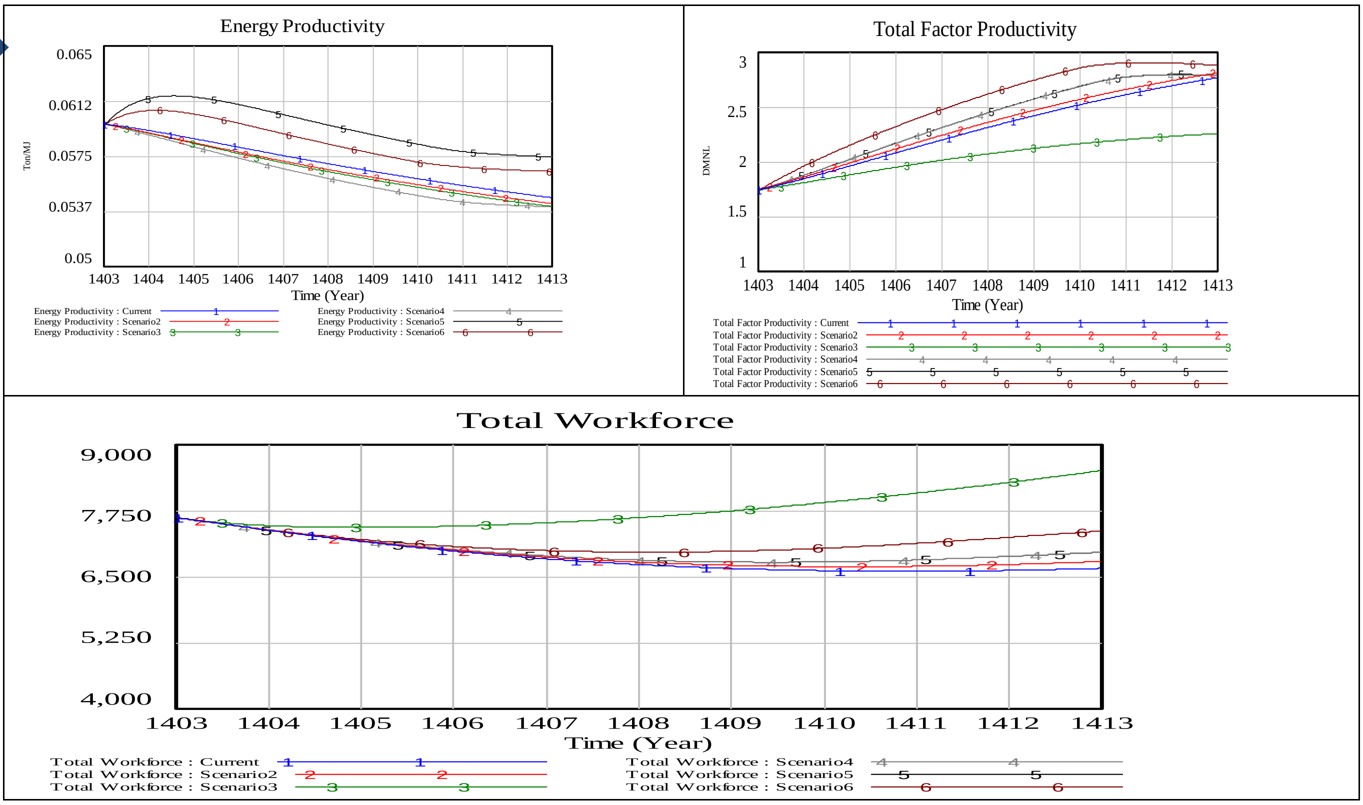


Figure 8. Results of the Managerial Scenario Analysis of the Concurrent Development of Research and Development Projects, Reduction of Work-Related Stress, and Increased Investment in the Technical and Educational Skills of the Workforce (Knowledge-Based Strategic Maturity) for Enhancing Productivity in Mining and Mineral Industries Organizations

The results of the sixth managerial scenario analysis reported in Figure 8 indicate that mineral extraction output increases in a clearly pronounced manner, with a steeper growth slope. The effects of investment in research and development projects are reflected in the form of more efficient technologies and improved extraction methods, while technical training exerts an equally significant impact. Profitability follows exactly the pattern expected from a powerful policy combination. Capital productivity exhibits an upward trend, and in Scenario 6 it is markedly higher than in all other scenarios, indicating that the real capacity of capital is released to a greater extent than ever before. Labor productivity is also one of the most salient features of this scenario, displaying a genuine and continuous upward trend. Employees become not only more efficient but also more accurate and creative. In this scenario, energy productivity also exhibits a different pattern compared with other scenarios. Unlike other scenarios, in which part of the trend typically remains downward or stagnant, Scenario 6 establishes a new equilibrium in which energy consumption decreases relative to production volume. Although this change is not as pronounced as the effects on production and profit variables, it nevertheless contributes to a higher degree of system maturity and stability. The improvement in total factor productivity is more significant and pronounced in this scenario than in any other, as all system components improve simultaneously. In effect, this scenario not only enhances performance levels but also upgrades the operational logic and functional structure of the system. In parallel, workforce size exhibits a different and more intelligent pattern. In previous scenarios, increased production was typically accompanied by an increase or at least stabilization in workforce size; however, in Scenario 6 this pattern changes. The workforce size trajectory indicates that the system moves toward growth without reliance on workforce expansion, aligning fully with modern production structures. In other words, the organization improves performance by making better use of its existing workforce rather than by increasing headcount. Targeted investment in specialized workforce training plays a central role in enhancing system performance, as improved employee skills enable the workforce to operate equipment more effectively and solve complex mining-related problems. Overall, Scenario 6 represents a combination of technology, skills, motivation, and knowledge. This scenario demonstrates that when investment in human capital and research and development is integrated with technological infrastructure, the system enters a stage of growth that surpasses previous capacities and achieves a level of performance unattainable under any of the preceding scenarios. Scenario 6 not only increases outputs but also transforms the quality and efficiency of processes, ushering the organization into a period of genuine maturity and capability.

Scenario 7: Expansion of Operational Programs in the Area of Safety and Risk Management (Safety-Based Operational Resilience)

In this scenario, it is assumed that from 2024 onward, the number of implemented operational programs in the field of safety increases to 20 programs per year. The implementation of this scenario, on the one hand, indicates that safety-related stoppages are largely prevented, leading to increased operational utilization, and on the other hand, reduces workforce stress and increases job satisfaction. In this scenario, policy focus shifts from hardware and technology toward safety, risk mitigation, and the stabilization of the work environment. While this change may initially appear operational in nature, at deeper levels it moderates and balances the behavior of the entire system, gradually controlling many latent disruptions in the production chain that manifested as stoppages, interruptions, and efficiency losses in previous scenarios. Accordingly, the results of the managerial scenario analysis of expanding operational programs in the area of safety and risk management, or safety-based operational resilience, for enhancing productivity in mining and mineral industries organizations are reported in Figure 9.

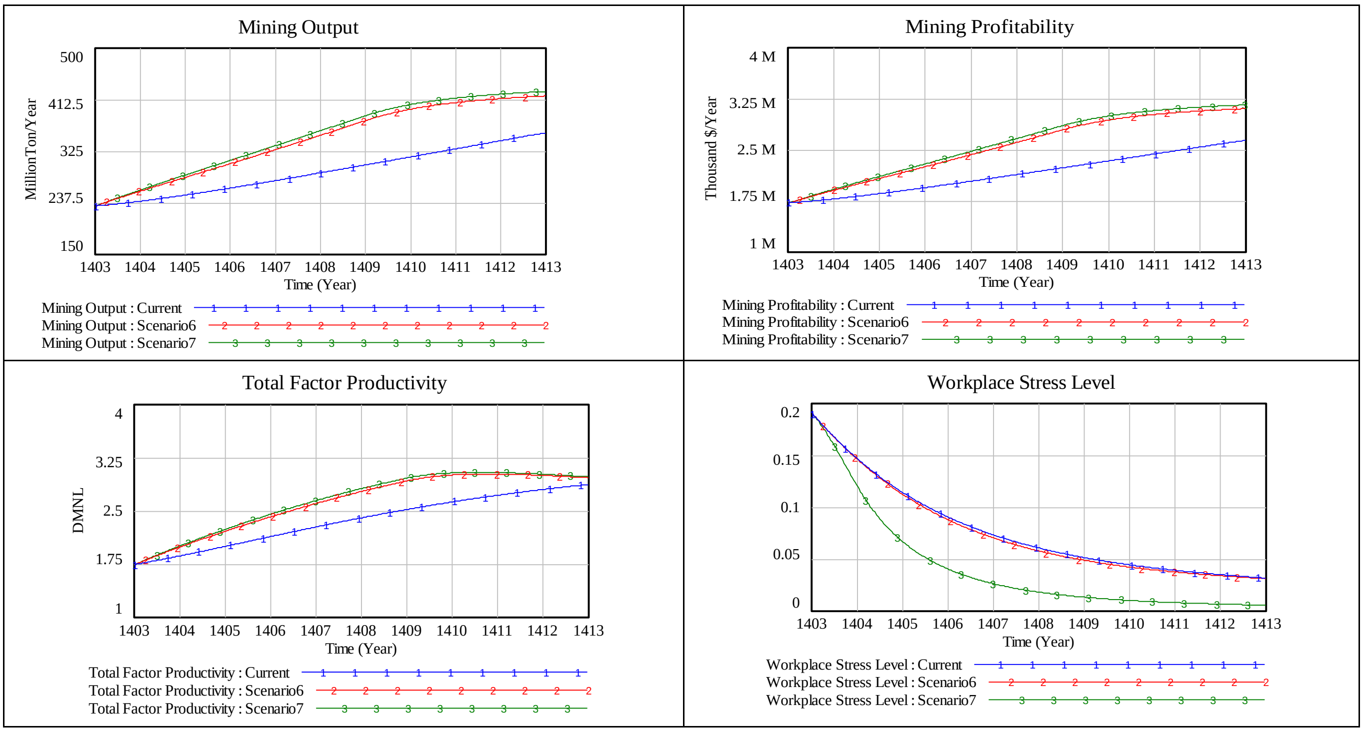
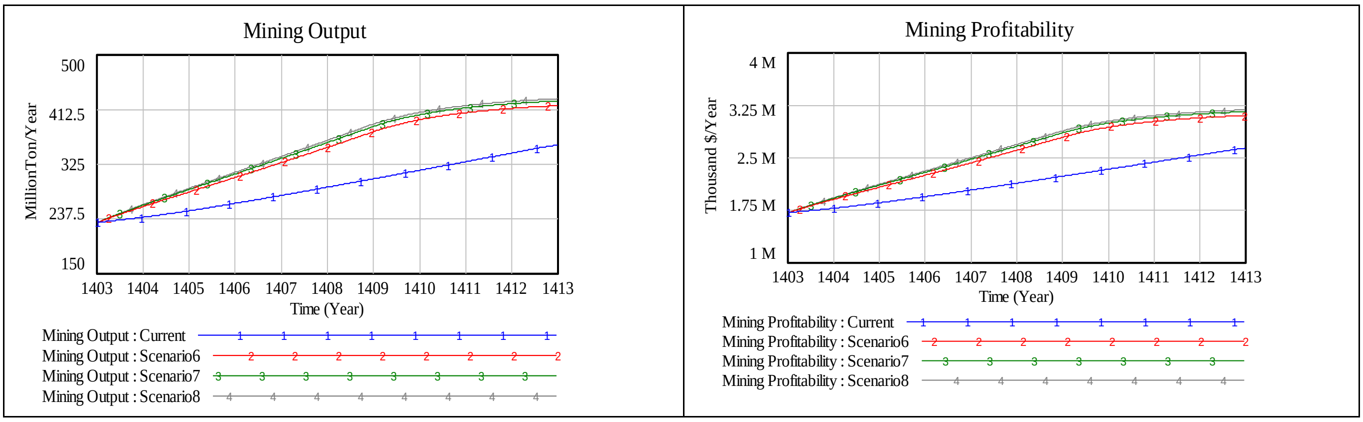


Figure 9. Results of the Managerial Scenario Analysis of Expanding Operational Programs in the Area of Safety and Risk Management (Safety-Based Operational Resilience) for Enhancing Productivity in Mining and Mineral Industries Organizations

The results of the seventh managerial scenario analysis reported in Figure 9 indicate that production in this scenario not only follows an upward trend but also grows more steadily than in the baseline condition. This growth is driven less by technological breakthroughs and more by the reduction of interruptions, accidents, and operational disorder. Rather than exerting pressure to increase output, the system facilitates natural growth by removing structural barriers; consequently, the mineral extraction curve rises more gradually but with greater reliability. Profitability exhibits a similar pattern, and unlike scenarios in which profitability gains stem from increased physical or technological capacity, in this scenario higher profits result primarily from the reduction of hidden costs—namely costs arising from accidents, damage, line stoppages, and workforce fatigue. In other words, the findings indicate that a safer work environment, even without heavy hardware investment, can generate higher economic returns. One of the most notable outcomes of Scenario 7 is observed in the total factor productivity trajectory. When environmental stress is reduced and operational risks are effectively managed, the entire system operates at a higher equilibrium level, and productivity gains emerge not from increased pressure on resources but from the release of the system's latent capacities. However, the central feature of this scenario is most evident in the level of workplace stress. The sharp and continuous reduction in stress—occurring with a steeper slope than in other scenarios—clearly demonstrates that safety programs are not merely ceremonial but have genuinely transformed the psychological and operational environment. This reduction in stress is immediately reflected in increased job satisfaction and enhanced workforce concentration, which indirectly strengthens all other performance indicators. Another key aspect of this scenario is that it relies on psychological and operational safety as the engine of productivity rather than solely on technology or capital-intensive investment. This scenario shows that development does not always depend on equipment acquisition or budget expansion; in some cases, eliminating fear, insecurity, and instability can yield outcomes comparable to those of high-cost scenarios. Overall, Scenario 7 presents a picture of an organization that has intelligently positioned safety as a competitive advantage. It demonstrates that risk and safety management are not merely costs, but rather hidden and highly effective investments in long-term productivity enhancement and performance sustainability.

Scenario 8: Increased Support for the Local Community (Social Synergy and Sustainable Development)

In this scenario, it is assumed that from 2024 onward, the budget allocated to supporting the local community increases by 40%, leading to improved production conditions and increased total productivity. Accordingly, the results of the managerial scenario analysis of increased support for the local community, or social synergy and sustainable development, for enhancing productivity in mining and mineral industries organizations are reported in Figure 10.



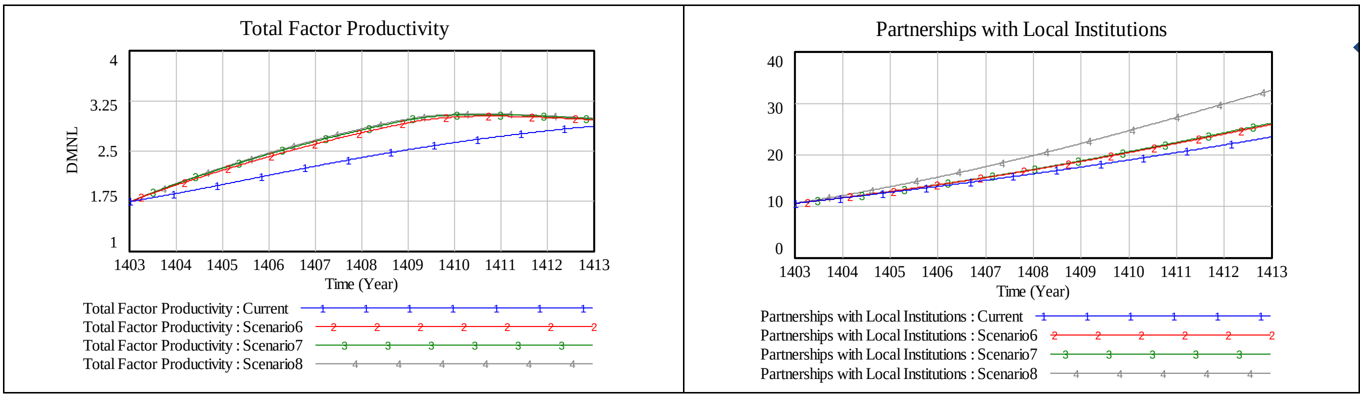


Figure 10. Results of the Managerial Scenario Analysis of Increased Support for the Local Community (Social Synergy and Sustainable Development) for Enhancing Productivity in Mining and Mineral Industries Organizations

The results of the eighth managerial scenario analysis reported in Figure 10 indicate that the output level of this scenario exceeds that of the baseline condition and even Scenarios 6 and 7. This increase does not occur in the form of abrupt growth, but rather as a smooth and sustainable upward trend, reflecting improvements in the overall operating environment of the mine, reduced environmental tensions, and enhanced cooperation with local stakeholders. Mine profitability confirms this behavioral pattern, as profitability under Scenario 8 exceeds that of the baseline and technically focused reform scenarios and approaches the level of the most effective scenarios. This finding suggests that social investment, although not directly allocated to production lines, creates conditions for increased profitability—both directly and indirectly—through reduced social risks, enhanced investment security, and an improved social image of the organization. In terms of total factor productivity, this scenario exhibits a favorable growth slope and shows a substantial gap relative to Scenarios 1 through 6. The level of cooperation with local institutions—considered the scenario-specific variable—demonstrates a fully upward and meaningful trend, with its divergence from other scenarios increasing over time. In other words, supportive policies toward the local community foster mutual trust, institutional participation, and synergy between the organization and its surrounding environment. Overall, Scenario 8 indicates that social investment, contrary to the initial perception that it may constitute an indirect cost, is one of the most effective levers for achieving sustainable improvements in mining system performance. This scenario demonstrates that sustainable development is not achieved solely through technology and equipment, but rather emerges from healthy relationships with the local community, the creation of social trust, and the alignment of organizational interests with those of the surrounding environment. Consequently, Scenario 8 presents a model of balanced growth in which increased production, profitability, and total productivity are achieved in parallel with enhanced social responsibility.

Discussion and Conclusion

Given the importance of improving productivity in mining and mineral industries organizations and the absence of prior research that applies a system dynamics approach to managerial scenario analysis in this field, the present study was conducted with the aim of designing an integrated simulation and managerial scenario analysis model to enhance productivity in mining and mineral industries organizations using a system dynamics approach.

The findings indicated that eight policy scenarios were simulated for the productivity-enhancement model in mining and mineral industries organizations, including technological infrastructure development, physical equipment modernization, improvement of organizational structures, intelligent energy management systems, research and development (R&D) activities, workforce technical skills, mine safety management programs, and support for the local community. The one-dimensional scenarios (Scenarios 2 and 3) had only a limited role in improving productivity in mining and mineral industries organizations, whereas the multidimensional scenarios (Scenarios 4 to 8) played a substantial role in improving productivity in these organizations. Although no study was identified on managerial scenario analysis for enhancing productivity in mining and mineral industries organizations using system dynamics, studies such as (15), (16), (17), (18), and (19) have examined productivity-related drivers in mining and mineral industries, and in several respects their results can be considered aligned with the present findings.

In explaining the managerial scenarios for improving productivity in mining and mineral industries organizations using a system dynamics approach, it can be stated that the present study simulated and analyzed a set of managerial scenarios (eight scenarios) to examine the dynamic behavior of the productivity system in mining and mineral industries organizations, each focusing on a specific dimension of organizational and operational development. The results showed that the studied system has an intrinsic capacity for growth; however, the combination of managerial interventions plays a decisive role in the magnitude and quality of this growth. The baseline scenario portrayed the continuation of the status quo and indicated that, in the absence of policy intervention, production and profitability increase gradually, yet challenges such as declining energy productivity and a gradual deterioration in the efficiency of certain resources remain persistent. In the baseline scenario (Scenario 1), which represents the continuation of existing conditions, no policy or managerial intervention was applied, and the system's natural behavior was examined over a 10-year horizon through 2034. In Scenario 2, the primary focus was on improving and developing technological infrastructure, which experienced a growth of 44.3%. The results demonstrated the direct role of this variable in improving performance and its indirect influence on other factors, including investment in physical equipment and improvements in organizational structures, and this scenario led to a 3.7% increase in R&D projects. In Scenario 3, centered on investment in physical equipment, the level of physical equipment development increased to approximately 30.8%, while technological infrastructure simultaneously experienced 46.7% growth. This finding suggests that hardware upgrading increases the concurrent need to strengthen technological and research infrastructure, and this scenario led to a 5.8% increase in R&D projects. In Scenario 4, which combined technology development with reforms in organizational and process structures, technological infrastructure increased to 53.3% and physical equipment to 6.4%, while the level of organizational structures and processes development increased by approximately 3.6%. This scenario indicates that the simultaneous combination of technological and organizational improvements moves the system into a phase of synergy and coordination, with effects clearly observable in improved macro-level productivity indicators, and it resulted in a 6.7% increase in R&D projects. In Scenario 5, a specific emphasis was placed on optimizing energy consumption, and the data showed that the energy consumption rate per unit of output decreased by approximately 5%. Although this reduction may appear numerically small compared with other variables, it plays an important role in system sustainability, contributing to the stabilization of productivity trends and reducing environmental pressures within the model, and this scenario also led to a 6.7% increase in R&D projects. In Scenario 6, as a comprehensive scenario, a combination of technology development, investment in R&D, and enhancement of workforce skills was implemented; in this scenario, technological infrastructure reached the highest level among all scenarios with 68.8% growth, and the budget for developing workforce technical skills increased by 40%. This combined policy–managerial package shifted the system out of linear growth and toward a level of maturity and efficiency in which capital productivity and labor productivity simultaneously reached their highest values compared with other scenarios, and this scenario produced a 64.7% increase in R&D projects. In Scenario 7, the main focus was on expanding operational safety programs and risk management; accordingly, the number of safety implementation programs increased by 133.5%, representing the largest increase among all variables. This finding indicates that safety and work-stress reduction policies have a direct influence on the stability of system performance and the reduction of operational downtime, and this scenario generated a 67.7% increase in R&D projects. In Scenario 8, designed with an emphasis on increasing support for the local community, cooperation with local institutions increased by approximately 38.6%. This finding suggests that social and institutional policies, through increasing mining-related activities and strengthening institutional relationships, directly and indirectly improve total system productivity, and this scenario resulted in a 69.1% increase in R&D projects.

The analysis of one-dimensional scenarios, including technological infrastructure development, investment in physical equipment, and energy consumption optimization, showed that each of these policies can generate localized and meaningful improvements. Technology development improved production, profitability, and capital productivity, yet its effect on energy productivity remained limited. Investment solely in physical equipment increased production capacity; however, in the absence of organizational reforms and workforce skill development, it led to a relative decline in total productivity. In contrast, energy optimization policies improved energy productivity, but because energy costs constitute a relatively limited share of total cost structures, their effects on macro productivity and profitability indicators remained constrained. Conversely, in combined scenarios where technology development was accompanied by organizational reforms, process improvements, investment in R&D, and enhancement of workforce technical skills, markedly better results were obtained. These scenarios demonstrated that synergy among technological, organizational, and human policies led to significant improvements in mine extraction, profitability, capital productivity, and labor productivity. Social and institutional scenarios further indicated that indirect interventions can also yield substantial impacts on system performance. Improving workplace safety reduced employee stress levels and operational downtime, thereby producing sustained performance improvement and production growth. Moreover, increasing interaction and participation with the local community and regional institutions, by generating social capital, reducing environmental conflicts, and increasing the social legitimacy of mining activities, created conditions for more stable growth in output and total productivity. Overall, the results indicated that the most effective pathway toward sustainable productivity in the mining industry is not the implementation of isolated policies, but rather the design and execution of integrated policy packages that simultaneously address technological, human, organizational, environmental, and social dimensions.

Overall, the combined scenarios—particularly Scenario 6—exhibited the highest level of positive changes relative to other scenarios, indicating that concurrent development of technological infrastructure, investment in equipment, enhancement of workforce skills, and improvement of working conditions produces organizational synergy that results in a significant increase in total productivity. In addition, the results of Scenarios 7 and 8 showed that variables such as risk management, safety, and engagement with the local community—although not directly defined within production operations—play an influential role in improving overall system performance by increasing system stability, reducing organizational tensions, and strengthening social capital. Consequently, the combined scenarios, especially Scenarios 6 to 8, demonstrated the greatest potential for producing sustainable improvements in total factor productivity, which can serve as a scientifically grounded basis for supporting managerial decision-making in this domain.

The results clarified the extent to which each scenario altered total productivity and the productivity of other inputs relative to the continuation of existing conditions. Model outputs confirm that one-dimensional and incremental policies (such as Scenarios 2 to 5), although capable of generating improvements, are insufficient for achieving maximum performance potential; instead, a comprehensive and integrated approach is essential. Scenario 6, which simultaneously targeted three pillars—technology (R&D), humans (skill development), and structure (intelligent systems)—successfully increased system-wide coordination and overall productivity and presented the strongest aggregated performance profile. Accordingly, it can be concluded that, to achieve sustainable development and competitiveness in the mining industry, firms should avoid focusing on a single domain and instead invest systematically and concurrently in human capital, technology, and innovation. The outcomes of increasing operational safety programs in Scenario 7 indicate that implementing such measures improves total productivity not only by directly reducing production stoppages but also indirectly by reducing employee stress and increasing job satisfaction. Similarly, in Scenario 8, strengthening collaboration with local institutions positively affected total productivity because constructive engagement with the local community can improve the business environment, enhance social legitimacy, and create implementation synergies.

This study aimed to design an integrated model of productivity drivers in mining and mineral industries organizations by employing a system dynamics approach and structural equation modeling, using methods such as grounded theory, fuzzy DEMATEL, structural equation modeling, and system dynamics. This integration enabled the study to follow a funnel-shaped pathway: beginning with qualitative data (grounded theory), then identifying and mapping causal relationships (fuzzy DEMATEL), subsequently conducting empirical testing, quantifying relationships, and validating model fit (structural equation modeling), and finally analyzing dynamic system behavior and developing managerial and policy scenarios (system dynamics). Thus, both theoretical validity (via grounded theory) and empirical/quantitative validity (via fuzzy DEMATEL and structural equation modeling), as well as practical decision support (via dynamic simulation), were ensured for the proposed model. The findings also showed that productivity is a multidimensional and dynamic construct that can reach a desirable level only through the integration of human, technological, structural, and managerial components.

Despite efforts to design and develop a comprehensive integrated model in the domain of productivity for mining and mineral industries organizations, the present study faced limitations that may affect the generalizability of results. Although the study employed system dynamics and structural equation modeling, these methods are partly dependent on modeling assumptions, and there is potential for subjective and perceptual bias at certain analytical stages. Additionally, time and financial resource constraints limited the possibility of deeper examination of all variables and the implementation of broader scenarios, requiring the study to focus on more critical variables. Moreover, the findings are based on mining and mineral industries in Iran, and generalization to other countries or industries should be undertaken cautiously, with comparative studies recommended. Given these limitations, future research may conduct comparative investigations across other industries to reveal structural and managerial differences in productivity and may collect international-level data to compare the productivity status of Iran's mining and mineral industries with that of leading countries. Furthermore, organizational culture and transformational leadership—key but less-studied factors in mining and mineral industries—warrant additional research, including specialized analyses of environmental sustainability and its relationship with productivity, particularly in waste recycling and energy consumption optimization. Consistent with the study's findings, multidimensional and combined scenarios were more effective than one-dimensional scenarios in improving productivity in mining and mineral industries organizations. Based on these results, initiatives such as mine digitalization, intelligent automation, green technologies, strategic human resource management, transformational leadership, and organizational culture development can contribute to higher productivity.

Acknowledgments

We would like to express our appreciation and gratitude to all those who helped us carrying out this study.

Authors' Contributions

All authors equally contributed to this study.

Declaration of Interest

The authors of this article declared no conflict of interest.

Ethical Considerations

All ethical principles were adheried in conducting and writing this article.

Transparency of Data

In accordance with the principles of transparency and open research, we declare that all data and materials used in this study are available upon request.

Funding

This research was carried out independently with personal funding and without the financial support of any governmental or private institution or organization.

References

1. Soto-Vazquez R. Life-cycle assessment in mining and mineral processing: A bibliometric overview. Green and Smart Mining Engineering. 2025;2(1):73-83. doi: 10.1016/j.gsme.2025.02.001.
2. Ericsson M, Lof O. Mining's contribution to national economies between 1996 and 2016. Mineral Economics. 2019;32:223-50. doi: 10.1007/s13563-019-00191-6.
3. Pakdel J, Erol I, Oztel A. Advancing digital transformation in the mining industry: A novel rough interval-valued neutrosophic DEMATEL approach to challenge interdependencies. Resources Policy. 2025;107:105663. doi: 10.1016/j.resourpol.2025.105663.
4. Molek-Winiarska D, Kawka T. Reducing work-related stress through soft-skills training intervention in the mining industry. Human Factors. 2024;66(5):1633-49. doi: 10.1177/00187208221139020.
5. Mahama UFA, King Boison D, Antwi-Boampong A. Assessing the effect of supply chain integration on operational performance: Exploring perspectives from the mining industry in Ghana. American Journal of Multidisciplinary Research & Development. 2024;6(6):40-54.
6. Zhang X. The impact of digital finance on corporate labor productivity: evidence from Chinese-listed companies. Journal of Industrial and Business Economics. 2023;50(3):527-50. doi: 10.1007/s40812-023-00273-1.
7. Xiao A, Xu Z, Wu T, Qin Y, Skare M. Technological progress and economic dynamics: Unveiling the long memory of total factor productivity. Economic Analysis and Policy. 2024;84:326-43. doi: 10.1016/j.eap.2024.09.004.
8. Firdaus M, Suryani E, Nadlifatin R, Tjahyanto A. Enhancing organizational culture and productivity through innovative performance appraisal: A design science research approach. Procedia Computer Science. 2024;234:1128-36. doi: 10.1016/j.procs.2024.03.108.

9. Suoniemi S, Terho H, Zablah A, Olkkonen R, Straub DW. The impact of firm-level and project-level IT capabilities on CRM system quality and organizational productivity. Journal of Business Research. 2021;127:108-22. doi: 10.1016/j.jbusres.2021.01.007.

10. Nguyen BN, Boruff B, Tonts M. Looking through a crystal ball: Understanding the future of Vietnam's minerals and mining industry. The Extractive Industries and Society. 2021;8(3):100907. doi: 10.1016/j.exis.2021.100907.

11. Nevries F, Wallenburg CM. Performance improvements in logistics outsourcing relationships: the role of LSP and customer organizational culture archetypes. International Journal of Operations & Production Management. 2021;41(12):1807-43. doi: 10.1108/IJOPM-02-2021-0122.

12. Somers J. Technologies to decarbonise the EU steel industry. European Commission, Joint Research Centre, 2022.

13. Yousefian M, Bascompta M, Sanmiquel L, Vintro C. Corporate social responsibility and economic growth in the mining industry. The Extractive Industries and Society. 2023;13:101226. doi: 10.1016/j.exis.2023.101226.

14. Malbon E, Parkhurst J. System dynamics modelling and the use of evidence to inform policymaking. Policy Studies. 2023;44(1):1-19. doi: 10.1080/01442872.2022.2080814.

15. Mayo-Alvarez L, Del-Aguila-Arcentales S, Alvarez-Risco A. Innovation using dynamic balanced scorecard design as an industrial safety management system in a company in the mining metallurgical sector. Journal of Open Innovation: Technology, Market, and Complexity. 2024;10(3):100362. doi: 10.1016/j.joitmc.2024.100362.

16. Agheli L, Hosseini MA. Actors affecting capital productivity in the Iranian mining sector. Quarterly Journal of Industrial Economics Researches. 2022;5(18):33-44. doi: 10.30473/jier.2022.8746.

17. Agheli L. Analyzing labor productivity in Iranian mines. Journal of Mineral Resources Engineering. 2020;5(4):37-52. doi: 10.30479/jmre.2020.12360.1363.

18. De Solminihac H, Gonzales LE, Cerda R. Copper mining productivity: Lessons from Chile. Journal of Policy Modeling. 2018;40(1):182-93. doi: 10.1016/j.jpolmod.2017.09.001.

19. Gamtessa S, Olani AB. Energy price, energy efficiency, and capital productivity: Empirical investigations and policy implications. Energy Economics. 2018;72:650-66. doi: 10.1016/j.eneco.2018.04.020.