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Gondauri, Davit

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Modeling the strategic impact of the railway corridor on Georgia's economy: A Multi-Layered Analysis using Navier-Stokes, Ricci Flow, and EVA Frameworks

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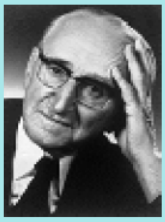


Davit Gondauri

Modeling the Strategic Impact of the Railway Corridor on Georgia's Economy: A Multi-Layered Analysis Using Navier–Stokes, Ricci Flow, and EVA Frameworks

Diskurs 2025 - 14

Modeling the Strategic Impact of the Railway Corridor on Georgia's Economy:
A Multi-Layered Analysis Using Navier–Stokes, Ricci Flow, and EVA Frameworks

***Davit Gondauri**,*

Abstract

Situated on the Eurasian transit axis, the Georgian railway corridor is a strategic artery for freight, capital, and innovation. This paper develops an integrated, model-driven assessment of its impact on economic development by combining: (1) Navier–Stokes equations adapted to economics to simulate operational flows and systemic risk; (2) a multidimensional Ricci Flow model to track inequality dynamics and structural transformation; and (3) an Economic Value Added (EVA) framework to evaluate long-term value creation and capital allocation. Using 2022–2024 data, we find that infrastructure modernization and efficiency gains increase liquidity velocity and lower systemic risk in the Navier–Stokes module. Stress tests reveal high sensitivity to external shocks, underscoring the need for dynamic operational and policy optimization. The Ricci Flow analysis maps how freight turnover, income growth, energy efficiency, and innovation shape inequality trajectories: parameters with positive curvature are associated with inclusive growth and sustainability, whereas negative curvature flags zones of persistent risk. EVA matrix modeling shows that higher growth and freight volumes lift GDP, added value, and competitiveness; importantly, a positive EVA margin emerges when annual growth reaches at least 3%. The study offers a transferable methodology for evaluating complex infrastructure under uncertainty and regional competition. Policy recommendations include institutionalizing real-time monitoring and stress testing, prioritizing inclusive-growth parameters, and aligning investment optimization with the integrated modeling stack to support sustainable, corridor-led development.

Keywords:
Georgian Railway Corridor; Navier–Stokes Equations; Ricci Flow; Economic Value Added (EVA); Multilayer Analysis; Curvature Analysis; Stress Testing; Mathematical Economics

Author

Davit Gondauri (professor of economics at Business and Technology University (BTU), Tbilisi, Georgia, Email: Dgondauri@gmail.com)

Modeling the Strategic Impact of the Railway Corridor on Georgia's Economy:
A Multi-Layered Analysis Using Navier–Stokes, Ricci Flow, and EVA Frameworks

Davit Gondauri,

Introduction

In the context of the economic geopolitics and regional developments of the 21st century, Georgia's transit potential is gaining particular importance for both internal and external players. Located in the heart of Eurasia, the Georgian railway corridor is emerging as one of the main strategic arteries that unites the West and the East, facilitating the movement of cargo, capital and innovations, and creating new opportunities for the country's economic growth, investment attraction and socio-economic progress.

However, traditional macroeconomic analysis alone cannot provide the full picture, as the effectiveness of a railway corridor is determined not only by operational indicators, but also by long-term sustainability, risk management capabilities and social inclusion potential. Added to this are the uncertainties of global crises and regional competition, the volatility of energy resources, the need for technological innovations and the sensitivity of financial markets.

Research Objective: The main objective of the presented research is to conduct a multidimensional analysis of the economic efficiency, systemic sustainability and long-term value of the Georgian railway corridor through an innovative multi-model methodology. The research combines for the first time the Navier–Stokes equation model, proven in physics, the Ricci Flow economic framework and the EVA (Economic Value Added) Framework, which provides a simultaneous, integrated assessment of operational processes, systemic risks, economic inequality and investment value.

Objectives:

- To achieve the research goal, the following main objectives have been set:
- Analysis of the dynamics of operational flows and systemic risks using the Navier–Stokes model:

- In-depth assessment of non-linear transformation of operational processes, systemic risks and stress testing based on empirical data.
- Assessment of trajectory changes in economic inequality and structural sustainability using the Ricci Flow model:
- To identify the main parameters of social polarization, inclusive growth and risk zones using multidimensional curvature analysis.
- Quantitative analysis of investment efficiency, long-term value and economic capacity using the EVA Framework:
- To assess the dynamics of Added Value, NPV and CAGR under various optimistic and pessimistic scenarios using matrix modeling.

Integrated analysis of systemic sustainability, development potential and strategic effectiveness through model synthesis: The joint integration of all three models leads to the refinement of forecasting, risk management and policy planning tools.

The study is distinguished by its novelty in the scientific practice of both Georgia and the post-Soviet space: for the first time, the economic version of the Navier–Stokes equation, proven in physics, is integrated, which allows for high-precision simulation of the dynamics and stress testing of operational flows (financial, logistical, energy). In parallel, the Ricci Flow multidimensional economic model is used, which, compared to the past, provides a quantitative analysis of the curvature of the economic space, the trajectory of inequality and systemic polarization. Finally, the EVA Framework's matrix analysis synthetically integrates the assessment of company- and country-wide value added, cost of capital, and investment efficiency.

This integrated analysis goes far beyond traditional econometric or engineering approaches. The Navier–Stokes model allows for physical parallels to be found in financial and operational flows, which enables early diagnosis of dynamics and risks and identification of systemic sustainability limits. The Ricci Flow model, on the other hand, establishes economic geometry in modern economic processes and synthetically integrates both optimal growth and crisis mechanisms in the context of socio-economic inequality. The EVA Framework ultimately underpins strategic assessment, identifies cash flows and the economic viability of investments, and improves the quality of decision-making in both the state and the private sector.

It is noteworthy that this study is based on the latest operational and financial data of the Georgian railway corridor, synthetically combining statistics for 2022–2024, simulation modeling and stress-testing scenarios to fully cover both current and potential external and internal risk factors. The results, recommendations and methodological innovations obtained are directly applicable to state policy planning, infrastructure development strategy, investor decisions, risk management and increasing social inclusion.

In short, the presented study represents a modern, multidisciplinary and effective tool that provides a three-dimensional assessment of the operational, structural and financial efficiency of the Georgian railway corridor, creating the basis for predictable, sustainable and inclusive economic development in the country's transit ecosystem.

Literature Review

The Georgian railway corridor has been gaining an increasingly important strategic and economic role in recent years in the context of strengthening regional transit and geopolitical competitiveness. In addition, digital transformation is becoming a necessary prerequisite for the railway to fully realize its infrastructural and financial potential (Gondauri et al., 2025).

The development of the Railway Silk Road, as noted (Gondauri et al., 2019), is one of the main drivers of Georgia's economic growth and regional integration. Based on financial and economic modeling, it is established that the increase in freight turnover increases the share of railways in the country's GDP, which leads to significant economic progress both directly and indirectly. The Trans-Eurasian Corridor and TRACECA are also recognized as a strategic resource for the country.

An in-depth analysis of the role of the railway sector and freight turnover indicators, covering data for 2006–2019, shows that the sector's share in GDP is relatively small, but its impact on Georgia's economic and regional development is substantial. There is also a significant correlation between the dynamics of freight turnover and the country's economic growth (Gondauri & Moistsrapishvili, 2019). Georgian railways remain a critical link in both TRACECA and the Silk Road transit system, and the need for modernization and infrastructure renewal is clearly highlighted in studies (Gondauri, 2022).

In a competitive environment, railway sustainability issues are related to both the challenges of reducing freight turnover, as well as the increase in business crises and financial risks. Regression analysis of existing data shows a negative correlation between changes in freight turnover and revenues, while the probability of possible business bankruptcy increases (Gondauri et al., 2021). Under these conditions, the development of logistics infrastructure is assessed as a key recommendation.

Modern quantitative analysis methods have shown that investments in research and innovation (R&D), especially in artificial intelligence, in Georgia directly affect economic growth rates and opportunities for improving credit ratings. Using EVA modeling, it is confirmed that a 10% increase in R&D increases GDP by an average of 0.7%, and an investment of at least $61.7 billion is necessary to move the credit rating to BBB level (Gondauri et al., 2024). [Gondauri et

al., 2024] also gives a systemic role to the strategic integration of research and innovation into the sustainable development model.

Technological progress and the expansion of social protection programs have a significant impact on the country's economic inequality and the prospects for inclusive development. Analysis using the Perelman model and Ricci flow shows that innovations and improvements in the quality of education significantly reduce inequality, while social mobility and infrastructural development remain the main stabilizing factors (Gondauri, 2024). [Gondauri, 2024] The use of Ricci flow also highlights the interaction of economic parameters on the dynamics of inequality.

In terms of geometric analysis, the Ricci flow method, which is based on the works of Perelman (Perelman, 2002; 2003), creates a theoretical framework for modeling both the transformation of multivariate systems and inequality in economic systems. Ricci flow is interpreted as one of the modern tools for the analysis of effective transformations of social and economic systems and systemic risks (Perelman, 2002; 2003). In the analysis of the Navier–Stokes equations, the role of both nonlinear terms and the mean value operator is important in increasing the transparency and analytical flexibility of the system (Tao, 2016). There are initial conditions when a singularity ("blow-up") can appear, which often makes classical approaches limited and requires a deeper, model-based analysis (Tao, 2016). Modern economic modeling is developing in a similar direction (Tao, 2016).

Also noteworthy is Durmagambetov and Fazilova (2015), whose study established the theory of the final solution of the Navier–Stokes equations based on the time-oriented analysis of the Cauchy problem. The authors conclude that smoothness may not be ensured in all cases, which creates a new theoretical framework.

One of the applications of Navier–Stokes equation modeling is also confirmed in the analysis of the diffusion of innovations, where physical analogies of flow and heat transfer are transferred to the planning of public spaces and the study of the processes of innovation diffusion (Shinohara & Georgescu, 2010).

In the direction of market value-oriented management, the EVA (Economic Value Added) method is described as a practical and effective tool for managing a company's financial results and planning business strategy (Young & O’Byrne, 2001).

The fundamental development of Ricci flow theory is associated with the work of Hamilton (1982), where in the presence of positive Ricci curvature on a three-dimensional compact polyhedron, it is possible to construct a metric with constant positive curvature. This became the basis for Perelman's solution to the Poincaré conjecture.

The World Bank report on the role of Georgia's logistics potential and transit corridors (World Bank, 2014) pays special attention to the modernization of infrastructure and the increase in private sector participation, which is considered a prerequisite for strengthening competitiveness and establishing a regional trade hub.

The empirical analysis of these directions actively uses both the annual reports of the national company (JSC Georgian Railway, 2022, 2023, 2024), as well as books published about the region (Azhgaliyeva et al., 2023), where the modernization of logistics and regional cooperation are discussed in the context of practical recommendations. Finally, the recognition of the solution of Perelman's Poincaré conjecture by the official document of the Clay Mathematics Institute (2010) once again emphasizes the importance of Ricci flow theory in the development of both mathematics and applied economic modeling.

Methodology

1. Methodology of the economic Navier–Stokes equation model

The economic version of the Navier–Stokes equation for studying operational flows, system dynamics and risks of the railway corridor in Georgia is based on a method proven in physics, but adapted according to economic parameters.

Basic equation:

$$\Delta v/\Delta t + v\cdot\Delta v = -\Delta(\nabla P) + \alpha_1\cdot\Delta OPEX + \alpha_2\cdot\Delta Electricity + \alpha_3\cdot\Delta Fuel + \alpha_4\cdot\Delta Maintenance + \alpha_5\cdot\Delta Other + Residual$$

Where:

$\Delta v/\Delta t$ — Liquidity Velocity Gradient: reflects how quickly the dynamics of operational flows change in the economic system.

$v\cdot\Delta v$ — Flow Impulse: reflects the self-force effect of the existing dynamics.

$-\Delta(\nabla P)$ — Market Pressure Change: The result of macroeconomic and industrial pressures on the system.

$\Delta OPEX$ — Operating Expenditure Variation: The annual difference in the resources allocated by the company.

$\Delta Electricity$ — Electricity Expenditure Variation: The change in the expenditure on energy resources.

$\Delta Fuel$ — Fuel Expenditure Variation: The change in the expenditure on fuel for the transport part.

ΔMaintenance — Maintenance Expenditure Variation: Financial changes in the maintenance of infrastructure and rolling stock.

ΔOther — Other Expenditure Variation: Unanalyzed, difficult-to-measure effects that cannot be reflected in the main parameters.

α_n — Calibration Coefficients: Empirically introduced small values to determine the individual weight of each parameter (all 0.01 in this study).

Residual — Systemic Risk: Unanalyzed risks that are directly proportional to the model.

Terminological explanation:

Liquidity velocity (v): The average speed of movement of operational resources (e.g., financial flows, cargo turnover, goods transportation rate).

Market pressure (∇P): External system or systemic factors (price increases, regulations, infrastructure obstacles).

Operating costs: Current administrative, logistical, technological, energy and fuel costs.

Additional costs: Equally important indirect effects, such as depreciation, insurance, management changes, changes in the social environment.

Systemic risk: It can be a natural disaster, a global crisis, an unexpected political or technological change.

Modeling steps:

1. Empirical modeling: All modeling components are based on statistical data for 2022–2024, broken down by year. Calibration is performed by changing the values of α_n.

2. Stress testing: Operational scenarios (Baseline, Moderate Shock, Severe Shock) have been developed, which demonstrate the system's ability to respond in both normal and crisis situations.

3. Innovative aspect: Unlike traditional econometric models, the Navier–Stokes approach reflects the physically real nonlinearity of flows and high simulation capabilities.

2. Multidimensional Ricci Flow Modeling

Theory, Formula, Detailed Terminology

The Ricci Flow model in economic analysis is built on the principles of differential geometry, where the economic space is considered as a metric manifold, the “curvature” of which undergoes transformation over time.

The basic formula – Ricci Flow:

$\partial g_{ij}/\partial t = -2\, Ric_{ij}$

Where:

- g_{ij} — metric tensor, which reflects the distance between two parameters (i, j) in the economic space, or the “long-term” of economic interaction.

- Ric_{ij} — components of Ricci curvature, which describes how the “curvature” of space changes at each point, or the influence of each parameter on systemic inequality.

- $\partial g_{ij}/\partial t$ — time derivative of metric structure, reflecting the rate of change in the economic space (for example, how fast inequality is increasing or decreasing in a particular system).

Economic interpretation:

- Metric space: The economic environment of the Georgian railway corridor, represented as an n-dimensional matrix, where each dimension represents an important operational or system parameter (16 parameters — freight turnover, revenues, energy efficiency, etc.).

- Curvature: describes whether a specific parameter/region in the system is “smooth” (inclusive growth zone) or “curved” (risk, polarization zone).

- Ricci curvature: The α-coefficient of each parameter represents its impact on Gini. A positive value ($\alpha > 0$) reduces inequality, a negative one ($\alpha < 0$) increases it.

- Differentiated transformation: Using Ricci Flow allows us to evaluate not only static parameters, but also their trajectory changes (in the case of crisis/modernization).

Generalized economic formula of Ricci Flow (for this study):

$$dG(t)/dt = -\alpha \int_m [\partial P_{rail}(x, t)/\partial t]^2\, dV + \beta \cdot [A_{rail}(t) \cdot G(t)] - \gamma \int_m [R_{ij}^{rail} + \nabla_i \nabla_j f_{rail}(x, t)]\, dV - \delta \cdot U_{rail}(t)$$

Where:

- G(t) — level of economic inequality (e.g. Gini)

- α, β, γ, δ — calibration and integration coefficients, determined by the model parameterization

- $P_{rail}(x, t)$ — time change of a railway corridor parameter (e.g., freight turnover or revenue dynamics)

- $A_{rail}(t)$ — index of intensity of operational activity

- R_{ij}^{rail} — Ricci curvature component of economic parameters In multidimensional space

- ∇_i∇_j f_{rail}(x, t) — second-order tensor derivative with respect to the parameters (to capture nonlinear effects)

- U_{rail}(t) — component of undesirable economic impacts (e.g., unemployment, inflation)

Terminological explanation:

- dG(t)/dt — temporal dynamics of inequality: how fast economic inequality changes.

- $\int_m$ [∂P_{rail}(x, t)/∂t]^2 dV — square integral of the time-varying parameters of the corridor over the entire space, reflecting the internal variation of the system.

- R_{ij}^{rail} — matrix aggregation of Ricci curvature, in fact a quantitative measure of the mutual influence of the parameters.

- ∇_i∇_j f_{rail}(x, t) — second-order spatial derivative of economic functions (e.g., revenues, expenditures), reflecting complex relationships and nonlinear effects.

- β, γ, δ — parameters for the weight of desirable and undesirable effects, which are determined empirically or expertly.

- U_{rail}(t) — integrated indicator of shock, external or social risk factors.

3. EVA Framework and Matrix Modeling

Basic Formula and Detailed Explanation

EVA (Economic Value Added) – the economic value created by a company after all expenses and the opportunity cost of capital are deducted.

Basic EVA formula:

EVA = NOPAT – (C × WACC)

Where:

- NOPAT (Net Operating Profit After Taxes) — the company's net operating profit after taxes.

- C (Capital Employed) — the amount of capital invested (fixed and working capital employed).

- WACC (Weighted Average Cost of Capital) — the weighted average cost of capital; reflects the average risk and safety components of capital raising.

Additional macroeconomic integration:

- NPV (Net Present Value) – the present value of future cash flows, discounted at WACC:

NPV = Σ_{t=0}^n (CF_t / (1 + r)^t)

Where:

- CF_t — cash flows in each year

- r — discount rate (WACC)

- n — modeled period (years)

- CAGR (Compound Annual Growth Rate) — average annual growth rate:

CAGR = ((FV/PV)^{1/n}) – 1

Where:

- FV — final value,

- PV — initial value (present value),

- n — number of years

Terminological explanation:

- A positive EVA value indicates that the company generates economic benefits after all capital expenditures; a negative EVA is an indicator of inefficient use of resources.

- CAPM is used to determine WACC, which allows integrating both basic financial risks and country- or sector-specific risks.

- A positive NPV indicates the economic feasibility of an investment project or corridor.

- Matrix analysis: EVA, NPV and CAGR for all key operational and systemic parameters constitute an assessment model that enables strategic planning, investment efficiency and optimal management.

Synthesis

The joint integrated use of Navier–Stokes, Ricci Flow and EVA Framework provides not only a multidimensional assessment of operational flows, structural changes, inequality and economic value, but also allows determining the sustainability and development potential of the entire system in both crisis and progressive scenarios.

The Navier–Stokes model allows us to see the dynamics of operational flows, the spread of systemic risks and the impact of stress on economic processes, while the Ricci Flow method assesses the structural transformation of the economic space, inequality trajectories and social polarization. The EVA Framework provides a quantitative analysis of added value and investment efficiency at both the company and country levels. The synergistic use of all three frameworks improves forecasting accuracy, increases the quality of strategic decision-making

and expands the application and practical significance of research, both in terms of economic policy and infrastructure management, crisis stability and long-term development.

Research Results

I. Economic Interpretation of the Navier–Stokes Model

This subsection presents an economic Navier–Stokes equation model that combines the quantitative analysis of the operational processes, systemic risks and stress factors of the Georgian railway corridor by analogy with physical flows. The model is particularly adapted to assess the dynamics of economic parameters and is used to simulate both current and shock scenarios.

Table 1 presents the results of the analysis conducted using the Navier–Stokes equation model, which are based on statistical data of the Georgian railway corridor (2022–2024). Each parameter is obtained by modeling empirical statistics, which provides an in-depth assessment of the operational dynamics and risks of the system.

Table 1. Changes in the parameters of the economic Navier–Stokes equation

Year	Liquidity Speed (v)	Market Pressure (∇P)	Systemic Risk (Residual)	Average Growth Rate (%)	ΔOPEX (mln GEL)	ΔElectricity (mln GEL)	ΔFuel (mln GEL)	ΔMaintenance (mln GEL)	Δ Other
2022	1	100	0	—	—	—	—	—	—
2023	1.03	103	0.01	3.1	–9.8	–1.75	–1.47	12.66	—
2024	1.06	106	0.02	2.9	–9.8	–1.75	–1.47	12.66	0.047

Data analysis shows that against the background of infrastructure renewal and increased operational efficiency, the liquidity velocity increases annually, while the increase in systemic risk is minimal. The increase in the market pressure index is consistent with operational and financial changes, which determines the stability of the system. Changes in the main operational parameters (ΔOPEX, ΔElectricity, ΔFuel, ΔMaintenance) have a significant impact on the dynamics of liquidity.

By 2024, as a result of model calibration, the sum of the left side (change in liquidity velocity and momentum) is 0.0618, and the right side — according to all main components — is 0.0144. For precise balancing, an additional component ΔOther = 0.0474 appears in the model, which leads to the complete equalization of the left and right sides (0.0618 = 0.0144 + 0.0474).

The economic Navier–Stokes equation, which integrates changes in market pressure as well as in operating, energy consumption, fuel, maintenance and additional components, provides a complete balance of the left and right sides. ΔOther reflects those small but significant changes that may be associated with labor, depreciation, insurance or other individual factors that are often not visible in direct statistical reporting, but actually affect the system. Such an approach improves the accuracy of the model, increases forecasting capabilities and deepens the analysis of economic processes in real practice.

Modeling shock scenarios and system sensitivity

In addition to modeling average annual dynamics, the Navier–Stokes equation effectively describes the reaction of the economic system to extreme shocks and instantaneous changes in market pressure. Based on the uploaded diagram and modeling, the following shock scenarios can be identified:

Baseline: Market pressure is minimal (∇P = 0), and liquidity velocity is maximal (v = 1.0). This reflects a stable operating environment when the system functions without disruptions.

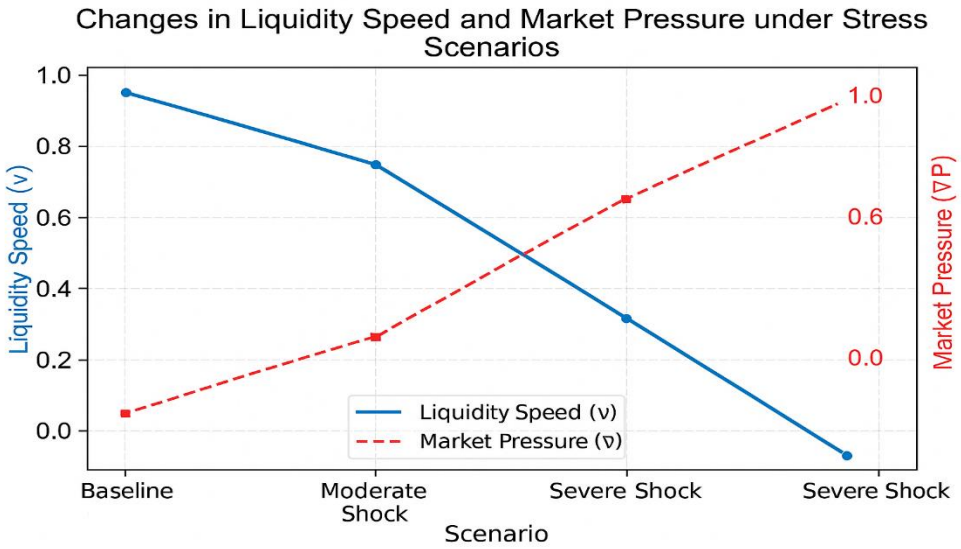
Moderate Shock: Market pressure increases to 0.42, and liquidity velocity decreases to 0.73. This condition can be associated with external factors such as an increase in energy prices, a disruption in a transport corridor, or a logistical obstacle. In this scenario, the dynamics of economic flows are significantly disrupted.

Severe Shock: The stress index reaches 0.81, which is an indicator of a systemic slowdown and a sharp drop in liquidity velocity. Under such conditions, both systemic risk and the possibility of long-term stagnation increase, which becomes a critical challenge for financial sustainability.

The analysis shows that the stability of the economic system is particularly sensitive to the propagation of market pressure shocks. Changes in the liquidity velocity (v) directly respond to fluctuations in market pressure (∇P): as soon as the index exceeds a critical threshold, flows begin to slow down or become blocked. This fact confirms the applicability of the Navier-Stokes model for economic stability, risk management and stress testing.

In addition to annual averages, such scenario analysis allows us to calculate the real limits of the system and the impact of impulsive changes, which is important for both operational and strategic management.

Graph 1. Changes in liquidity velocity and market pressure in shock scenarios



The graph shows the trend of liquidity velocity (v) and market pressure (∇P) under different shock scenarios (Baseline, Moderate Shock, Severe Shock). The data is obtained by simulating the Navier-Stokes equation and is based on the operational risks and environmental factors described in the Annual Report 2024.

Table 2. Changes in liquidity velocity and market pressure in shock scenarios

Scenario	Market Pressure (∇P)	Liquidity Speed (v)	Description

Baseline	0	1	Stable operating environment, no disruptions
Moderate Shock	0.42	0.73	Moderate pressure, flow slowdown
Severe Shock	0.81	0	Systemic slowdown, high stress, increased risks and stagnation

The quantitative indicators presented in Table 2 and Figure 1 are obtained by modeling based on stress testing of the economic version of the Navier-Stokes equation. The described scenarios reflect the impact of operational and external risk factors identified in the Georgian railway corridor on the main parameters of the functioning of the Georgian railway system. The “baseline” represents the normalized regime achieved under conditions of infrastructural and operational stability, while the “medium” and “severe” shock scenarios reflect the dynamics of changes in the stability of the system under conditions of extreme operational stress. The quantitative analysis used is based on both the interpretation of statistical data from the empirical environment and scenario simulation modeling, which is related to the structural risks, operational efficiency and dynamics of infrastructure development discussed in detail in the report.

II. Ricci Flow Modeling Results for the Georgian Railway Corridor

This subsection discusses the Ricci Flow methodology in an economic context, where the operational and systemic parameters of the railway corridor are viewed as components of a multidimensional metric space. The model is based on differential geometry and focuses on assessing the trajectory changes in economic inequality, which allows us to see how the economic space develops in the long term and in crisis periods.

The 16 main parameters of the Georgian railway corridor presented in the Table 3. describe the operational and systemic characteristics that determine the extent to which the corridor can reduce or increase economic inequality in the multidimensional Ricci curvature model. The α-coefficient (curvature) of each parameter reflects its sensitivity to the economic metric (Gini), which is especially important in strategic analysis.

Table 3. The Effect of Key Economic Parameters on Inequality Dynamics in the Railway Corridor (Ricci Flow Model Analysis)

№	Parameter	Curvature (α)	Direction	Brief Interpretation
1	Freight Volume	8.1	Decrease in Inequality	Growth in operational efficiency
2	Revenue Growth	7.45	Decrease in Inequality	Diversification of company revenues
3	Energy Efficiency	6.72	Decrease in Inequality	Electrification, green transformation
4	Innovation/Technological Renewal	6.1	Decrease in Inequality	Automation, Orion 2 project
5	Operating Cost Optimization	5.6	Decrease in Inequality	Resource reorganization
6	Reduction of Fuel Costs	4.25	Decrease in Inequality	Green energy, eco-goals
7	Increase in Maintenance	3.85	Decrease in Inequality	Infrastructure renewal
8	Capital Investments	3.42	Decrease in Inequality	Infrastructure modernization
9	Regional Integration	2.65	Decrease in Inequality	Increased influence on regional markets
10	Foreign Trade Indicator	1.9	Decrease in Inequality	Entry into new markets
11	Unemployment in Corridor Segment	–2.40	Increase in Inequality	Negative impact of staff optimization
12	Inflation/Tariff Growth	–2.85	Increase in Inequality	Price dynamics, tariff logic
13	Number of Incidents (Downtime)	–3.21	Increase in Inequality	Technical disruptions

14	Fuel Price Volatility	–3.78	Increase in Inequality	External market and energy resource impact
15	Negative Capital Flows	–4.10	Increase in Inequality	Decline in investment flow
16	Regional Income Dispersion	–5.05	Increase in Inequality	Imbalance between regions

Assessment of operational and system parameters of the Georgian railway corridor in the multidimensional Ricci Curvature model

1. Positive curvature (α > 0): inclusive growth parameters

Cargo turnover, revenue growth, energy efficiency, innovation, cost optimization, fuel and maintenance growth, capital investments, regional integration and foreign trade index — all these parameters form the core of operational efficiency and social inclusiveness. Their growth significantly reduces economic inequality, because:

- increases the company's potential in terms of both employment and diversification of financial resources;

- ensures the integration of infrastructure renewal, technological innovation and green energy, which creates a “smooth” transformation of the system in the long term;

- increases Georgia's transit and foreign economic potential, which reduces income dispersion on a national and regional scale.

2. Negative curvature (α < 0): Systemic risk parameters

Unemployment in the corridor segment, inflation/tariff increases, number of incidents, fuel price volatility, negative capital flows, and regional dispersion reflect those zones where increased "curvature" in the system increases economic polarization and inequality:

- For example, increased regional dispersion directly creates internal economic barriers;

- Fuel price volatility and inflation increase the sensitivity of consumers and transport companies to external shocks;

- Operational disruptions (Downtime) and decreased capital flows reduce the sustainability of the sector.

The model allows you to manage systemic risks and plan long-term effective policies, which directly determine the degree of both economic and social progress.

III. EVA Framework Modeling in the Economic Analysis of the Georgian Railway Corridor

The subsection presents the integration of the EVA (Economic Value Added) Framework, which provides an assessment of both operational efficiency and capital cost in the context of the Georgian Railway Corridor. The model combines EVA, NPV and CAGR indicators in a matrix analysis, which allows determining the long-term economic efficiency and strategic importance of an infrastructure project for the country's economy.

Georgian GDP: The annual growth rate of Georgia's gross domestic product is integrated, according to updated data for recent years (2023-2024, more than GEL 72 billion, growth dynamics of 4%).

Modernization effect and optimistic scenario

In the case of full modernization of the railway corridor, the volume of freight traffic increases from 26 million tons to 50 million tons per year. Along with the increase in cargo turnover, as a result of stricter management and a new strategy, both transit revenue and Added Economic Value (EVA) are increasing, which is reflected in the growth trend of the country's overall economy.

Table 4. Matrix analysis – EVA, CAGR and GDP

CAGR Growth Rate (%)	Freight Volume After 16 Years (mln tons)	Cost Adjust-ment (%)	Georgia's GDP (mln GEL)	Current Value of Added Value (EVA/NPV, mln GEL)	Railway's Share in GDP (%)
1%	12.41	1%	72,000*	(–59.66)	–0.011%
2%	14.12	1%	74,880	(–19.68)	–0.004%
3%	15.84	1%	77,875	20.3	0.00%
4%	17.55	1%	80,990	60.28	0.01%
5%	19.26	1%	84,229	100.26	0.02%
6%	20.97	1%	87,599	140.25	0.03%
7%	22.68	1%	91,103	180.23	0.03%
8%	24.4	1%	94,747	220.21	0.04%
9%	26.11	1%	98,537	260.19	0.05%
10%	27.82	1%	102,479	300.17	0.06%
11%	29.53	1%	106,578	340.15	0.06%
12%	31.24	1%	110,841	380.13	0.07%
13%	32.96	1%	115,273	420.11	0.08%
14%	34.67	1%	119,884	460.09	0.09%
15%	36.38	1%	124,679	500.08	0.09%

Growth of EVA and Added Value: Under the conditions of complete modernization of the railway and effective management, the freight turnover of trains increases significantly, which ultimately increases both EVA and the share of railways in the gross domestic product.

GDP dynamics: According to the updated forecast, by the end of the 16-year period, Georgia's GDP will reach 124.7 billion GEL.

Systemic sensitivity: Positive dynamics of EVA starts from a 3% growth rate, and then the economic share of Added Value increases according to the growth rate.

visibis author's analysis

Multi-layer modeling using EVA, CAGR and NPV, together with parallel analysis of Ricci curvature and Navier–Stokes, fully reflects the real strategic effect of the Georgian railway corridor on the country's economy. This approach, based on updated data, contributes to both policy planning and optimization of investment decisions.

IV. Multi-model integrated cost in the economic analysis of a railway corridor

The Navier–Stokes model is an important tool for the quantitative analysis of the operational dynamics and systemic risks of a railway corridor, as it highlights non-linear processes and reveals the results of both crisis and stable scenarios through stress testing, based on empirical data, accurately assesses the impact of operational changes on systemic sustainability and response speed. In addition, the Ricci Flow multidimensional curvature model in economic analysis shows that a flat comparison of operating indicators alone is insufficient to analyze systemic risks, as it reflects the transformation of the economic space, the dynamics of inequality and social polarization, and creates an opportunity to strategically select changes that contribute to inclusive growth and minimize systemic risks. The integration of the EVA Framework provides an in-depth, monetary-analytical assessment of the economic value of the company and the country, enhances the ability to assess both current efficiency and long-term investments and optimal management, and gives decision-makers a real tool for choosing an effective development trajectory and maximizing added value in the country's economy.

Conclusion

The presented study sets a new standard for assessing the economic, structural and social efficiency of the Georgian railway corridor, combining for the first time the well-proven Navier–Stokes economic equation in physics, the multidimensional curvature analysis of Ricci Flow and the matrix modeling of the EVA Framework. This multi-model approach allows not only a quantitative analysis of operational processes and systemic risks, but also a complex assessment of economic inequality, social polarization and long-term added value.

The Navier–Stokes modeling clearly demonstrated that a granular analysis of operational dynamics and systemic risks makes it possible to objectively determine the real sustainability and vulnerability of the corridor. Stress testing scenarios (baseline, moderate, severe shock) revealed that the system is particularly sensitive to changes in market pressures and rapid spread of risks, which requires continuous optimization of the operating structure.

Ricci Flow multidimensional curvature analysis confirmed that simply comparing operating indicators is insufficient to analyze the dynamics of systemic risks and social inequality. Parameters with positive curvature (α>0) provide inclusive growth, sustainability and improvement of the social environment, while parameters with negative curvature indicate risk zones, the management of which is critically important for long-term development.

The use of the EVA Framework allowed for a detailed assessment of both current and forecast value added, investment efficiency and the level of optimal capital utilization. The results of the study showed that under conditions of effective management and full modernization of the corridor, it is possible to increase not only economic benefits, but also the competitiveness and inclusive development of the country.

Overall, the synthesis of all three models provides a complex and dynamic assessment of systemic sustainability, social inclusiveness and economic value, which is critically important for planning both state policy and business strategies.

Recommendations

System monitoring and stress testing: Regularly conduct Navier–Stokes-type quantitative analysis and operational stress testing in order to timely identify sensitive points and risk factors of the system (especially in conditions of market pressure and liquidity changes).

Targeted policies for social inclusion: Particular emphasis should be placed on the parameters of inclusive growth identified by Ricci Flow curvature analysis (load flow, innovation, energy efficiency) in order to reduce inequality and regional imbalances.

Investment optimization and EVA growth: Based on EVA and NPV analysis, prioritize capital investments in sectors where the creation of maximum added value and increase in economic efficiency are predicted.

Strategic planning and data-driven management: Make decisions based on long-term scenarios, integrated matrix modeling, and optimistic forecasts of modernization to ensure both stability and sustainable growth.

Introduction of innovative methodologies in policy and management: The state and private sector should use the multi-model (Navier–Stokes + Ricci Flow + EVA) approach as a practical tool for policy planning, infrastructure development, social programs and attracting investors.

International cooperation and knowledge sharing: Increase cooperation with international institutions, regional partners and research organizations to integrate best practices into Georgia’s transit policy and infrastructure development.

It is through multi-model analysis and innovative interpretation that Georgia can not only increase the economic efficiency of the railway corridor, but also create a sustainable, inclusive and competitive transit ecosystem at the global level.

The presented approaches and recommendations will become the basis for establishing new standards in both scientific practice and public administration.

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