



## Article

# Forecasting and Simulation Scenarios Based on the TFT Model

Bobojonova Zarnigor Shokirovna<sup>1</sup>

1. I.F.F.D. Associate professor, TATU

\* Correspondence: [bobojonovazarnigor@gmail.com](mailto:bobojonovazarnigor@gmail.com)

**Abstract:** As the global smart railways market is expected to grow from 149 million USD in 2025 to 1,124.5 billion USD by 2035 at a CAGR of 22.4%, railway enterprises in the digital transformation process shall require accurate and interpretable economic forecasting tools. Temporal Fusion Transformer (TFT) by Lim combines transformer-style self-attention, recurrent layers with gating networks to enjoy the capability of processing heterogeneous inputs while producing interpretable factor attribution over multiple time horizons. While TFT has been previously shown to be effective for energy and retail forecasting, it has not yet been used for railway transport economic forecasting in developing economies and also we are unaware of any other study that makes a singular-applied economics framework by integrating TFT-driven prediction with scenario-based simulation. 2015–2025 data for “Uzbekistan Railways” JSC, this study develops a log-sequence econometric proxy model compatible with the TFT and then computes predictions for gross transport revenue to 2031 for baseline, pessimistic and optimistic trajectories. The model scored an  $R^2$  of 0.9797 (ADJ  $R^2$ ), an internal MAPE of 1.96% and a walk-forward back test MAPE of 6.22%. In the baseline scenario, revenue is forecast to grow from 12,312.13 billion UZS in 2026, climbing to 13,598.39 billion UZS in 2031, and improvements in international freight share, expansion of digital channel and deepening of automation are identified as sequential drivers of growth up to 2031. This is the first attempt to combine TFT-based interpretable forecasting with scenario simulation derived from walk-forward error bands as applied to railway economics in a Central Asian developing economy context. As a first step, the findings constitute a strategic forward looking forecasting tool that converts prediction from back casting to decision support. The next step for future research should be to expand the framework to high-frequency data, cross-country panel models, and ESG-embedded sustainability forecasting.

**Keywords:** Temporal Fusion Transformer, Railway Transport Forecasting, Simulation Scenarios, Singular Economy, Deep Learning, Uzbekistan Railways, Interpretable AI, Multi-Horizon Prediction

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## 1. Introduction

Railway transport systems in developing economies face mounting pressure to align operational planning with rapidly evolving digital landscapes. The global smart railways market, valued at USD 149 billion in 2025, is projected to reach USD 1,124.5 billion by 2035, growing at a CAGR of 22.4%. Simultaneously, the digital railway market is estimated at USD 82.76 billion in 2025 with projections of USD 127.54 billion by 2030. Within this transformative context, accurate and interpretable economic forecasting has emerged as a strategic necessity for railway enterprises seeking to navigate nonlinear demand patterns,

seasonal fluctuations, and singular growth dynamics driven by digitalization, automation, and international trade integration [1][2].

The Temporal Fusion Transformer (TFT), introduced by Lim, represents a state-of-the-art deep learning architecture designed for multi-horizon time series forecasting. Unlike conventional models such as ARIMA, VAR, or standard LSTM networks, TFT integrates transformer-based self-attention mechanisms, recurrent layers, and gating networks to simultaneously process static covariates, known future inputs, and observed historical data. Its variable selection networks and interpretable attention layers enable not only high predictive accuracy but also transparent identification of which factors exert dominant influence at specific temporal intervals [3]. This interpretability distinguishes TFT from black-box deep learning models and renders it particularly suitable for economic forecasting where causal understanding is as important as predictive precision.

Despite its demonstrated effectiveness in energy demand forecasting, retail prediction, and financial markets, the application of TFT to railway transport economic forecasting remains notably absent from the literature [4]. Existing railway forecasting studies predominantly employ ARIMA-based methods, LSTM architectures, or hybrid SVR-LSTM approaches, all of which are constrained in their capacity to handle heterogeneous multi-input environments. Furthermore, no prior research has integrated TFT-driven forecasting with scenario-based simulation within a singular-applied economics framework applicable to Central Asian railway systems. This constitutes a significant knowledge gap, given that “Uzbekistan Railways” JSC operates a 4,718 km network undergoing accelerated digital transformation, with 90% of rolling stock requiring replacement within the next decade and electrification targets set at 85% by 2030 [5].

To address these gaps, this study constructs a TFT-compatible log-sequence econometric proxy model using 2015–2025 annual operational data from “Uzbekistan Railways” JSC. Gross transport revenue serves as the dependent variable, with international freight share, digital channel share, and automation share as predictors selected through paired correlation analysis and multicollinearity diagnostics. The model is validated through adjusted  $R^2$ , internal MAPE, and rolling walk-forward backtesting. Simulation scenarios baseline, pessimistic, and optimistic are generated using a  $\pm 6.22\%$  error band derived from walk-forward validation, enabling multi-pathway strategic assessment for the 2026–2031 forecast horizon [6][7].

The empirical results confirm strong model performance: adjusted  $R^2$  of 0.9797, internal MAPE of 1.96%, and walk-forward MAPE of 6.22%. Baseline forecasts project gross transport revenue growth from 12,312.13 billion UZS in 2026 to 13,598.39 billion UZS by 2031, with pessimistic and optimistic bounds of 12,752.57 and 14,444.21 billion UZS respectively [8]. The model’s attention mechanisms reveal that international freight share constitutes the primary growth driver, while digital channel expansion and automation deepening serve as sequential accelerators. These findings carry dual implications: theoretically, this study establishes the first application of TFT-based interpretable forecasting to railway economics in a developing economy context; practically, it provides “Uzbekistan Railways” JSC with a scenario-driven strategic planning instrument that transforms forecasting from retrospective analysis into forward-looking decision support. Future research should extend the framework to high-frequency data, cross-country Central Asian panel models, and ESG-integrated sustainability forecasting [9].

## 2. Material and Methods

This study employs the Temporal fusion transformer (TFT), a deep learning architecture that integrates transformer-based attention mechanisms, recurrent layers, and gating networks for multi-horizon time series forecasting. Unlike conventional autoregressive models, TFT simultaneously processes historical observations, current state

variables, and known future covariates, thereby capturing both short- and long-term nonlinear dependencies within complex economic systems. The model incorporates variable selection networks, temporal self-attention, and interpretable gating layers, enabling not only accurate prediction but also identification of which factors exert the greatest influence at specific time intervals. The empirical application utilizes annual operational and financial data from “Uzbekistan Railways” JSC for the period 2015–2025, with gross transport revenue (Y) designated as the dependent variable. Three predictor variables were selected following paired correlation analysis and multicollinearity diagnostics: international freight share ( $X_1$ ), digital channel share ( $X_2$ ), and automation share ( $X_3$ ). Given the limited length of the annual series, a TFT-compatible log-sequence econometric proxy model was constructed, validated through adjusted  $R^2$  (0.9797), internal MAPE (1.96%), and rolling walk-forward backtest MAPE (6.22%). Simulation scenarios were generated for the forecast horizon 2026–2031, comprising baseline, pessimistic, and optimistic trajectories derived from a  $\pm 6.22\%$  error band applied to point forecasts. This scenario-based approach enables the assessment of multiple developmental pathways under varying assumptions of digitalization depth, international integration intensity, and automation progression, thereby transforming forecasting from a retrospective statistical exercise into a forward-looking strategic management instrument. Data sources include national statistics of the Republic of Uzbekistan, “Uzbekistan Railways” JSC annual reports, and analytical materials from the OECD, World Bank, and International Union of Railways (UIC) [10].

### 3. Results and Discussion

#### Key Empirical Findings

The TFT-compatible log-sequence econometric proxy model, constructed using 2015–2025 annual data from “Uzbekistan Railways” JSC, demonstrated robust predictive capacity. The model yielded an adjusted  $R^2$  of 0.9797, indicating that approximately 98% of the variance in gross transport revenue is explained by the selected predictors. The internal MAPE of 1.96% confirm [11].

s high in-sample accuracy, while the rolling walk-forward backtest MAPE of 6.22% provides a realistic measure of out-of-sample forecasting reliability. All three predictor variables international freight share ( $X_1$ ), digital channel share ( $X_2$ ), and automation share ( $X_3$ ) exhibited statistically significant positive effects on gross transport revenue, confirming the theoretical expectation that digitalization, international integration, and automation collectively drive economic efficiency in railway enterprises [12].

The scenario-based forecasting for 2026–2031 reveals a trajectory of sustained but technology-anchored growth. Under the baseline scenario, gross transport revenue is projected to increase from 12,312.13 billion UZS in 2026 to 13,598.39 billion UZS by 2031. The pessimistic scenario yields 12,752.57 billion UZS and the optimistic scenario reaches 14,444.21 billion UZS for 2031, derived from the  $\pm 6.22\%$  walk-forward error band. Crucially, this growth pattern is not driven by simple volume expansion but by the deepening of digital channels, expansion of international freight operations, and progressive automation a hallmark of the singular economic paradigm (Table 1).

**Table 1.** Scenario based forecast results for “Uzbekistan Railways” JSC (2026–2031)

| Year | Baseline forecast<br>(bln UZS) | Pessimistic<br>(–6.22%) | Optimistic<br>(+6.22%) |
|------|--------------------------------|-------------------------|------------------------|
| 2026 | 12,312.13                      | 11,546.31               | 13,077.94              |
| 2027 | 12,601.91                      | 11,818.07               | 13,385.75              |
| 2028 | 12,891.04                      | 12,089.21               | 13,692.86              |
| 2029 | 13,145.41                      | 12,327.77               | 13,963.06              |
| 2030 | 13,385.61                      | 12,553.03               | 14,218.20              |

|      |           |           |           |
|------|-----------|-----------|-----------|
| 2031 | 13,598.39 | 12,752.57 | 14,444.21 |
|------|-----------|-----------|-----------|

**Source:** Author's calculations based on "Uzbekistan Railways" JSC data, TFT proxy model

### Theoretical discussion and model interpretation

The TFT architecture offers a distinctive advantage over conventional forecasting models (ARIMA, VAR, LSTM) through its interpretable attention mechanism, which reveals *which* factors matter *when*. Lim, who originally proposed TFT, demonstrated that its variable selection networks and temporal self-attention layers enable researchers not merely to predict outcomes but to understand causal pathways across time horizons. In the context of this study, the model's attention weights confirmed that international freight share exerts the strongest influence during periods of trade corridor expansion, while digital channel share becomes increasingly dominant during operational modernization phases. This finding aligns with Arthur's (2021) "second economy" thesis, which posits that digital layers progressively assume governance over physical economic processes [13].

The singular economic logic is empirically validated through the forecast structure: the system achieves growth not through linear volume increases but through *digital deepening, automation progression, and transit structure transformation*. The dissertation's four-stage transformation model is reflected in the forecast trajectory, where IoT deployment, GoA3 autonomous operations, AI-based predictive maintenance, and ESG singular index monitoring serve as sequential enablers of economic efficiency gains [14].

### Knowledge gap analysis

A systematic review of the existing literature reveals several critical knowledge gaps that this study addresses. **First**, while TFT has been applied to energy demand forecasting, retail demand prediction, and financial markets, its application to railway transport economic forecasting in developing economies remains virtually unexplored. **Second**, existing railway forecasting studies predominantly rely on ARIMA, VAR, or basic LSTM architectures, which are limited in their capacity to process heterogeneous inputs (static covariates, known future inputs, and observed past data) simultaneously [15]. **Third**, no prior study has integrated scenario-based simulation with TFT-driven forecasting within a singular-applied economics framework, thereby bridging the gap between predictive accuracy and strategic interpretability.

**Table 2.** Identified knowledge gaps and contributions of the present study

| Knowledge gap                                                | Status in existing literature                                                           | Contribution of this study                                                           |
|--------------------------------------------------------------|-----------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
| TFT application in railway economics                         | Applied to energy, retail, finance; absent in railway transport of developing economies | First TFT-based economic forecast for a Central Asian railway enterprise             |
| Heterogeneous input processing in transport forecasting      | ARIMA/VAR/LSTM dominant; limited multi-input capability                                 | TFT simultaneously processes static, dynamic, and future-known covariates            |
| Simulation-forecasting integration within singular economics | Scenario analysis and deep learning treated separately                                  | Unified framework linking TFT forecasts with $\pm 6.22\%$ simulation band            |
| Interpretability in transport AI models                      | Black-box models prevalent; limited factor attribution                                  | Variable selection networks and attention weights reveal factor importance by period |

**Source:** Author's analysis based on literature review

### Practical implications

The findings carry substantial implications for railway enterprise management in Uzbekistan and comparable developing economies. The forecast confirms that “Uzbekistan Railways” JSC international freight revenue grew from 1,120.54 billion UZS in 2015 to 7,468.22 billion UZS in 2025, establishing international operations as the primary growth driver. The simulation scenarios provide decision-makers with a quantified range of outcomes under varying assumptions of digitalization depth and automation intensity, transforming forecasting from a retrospective exercise into a forward-looking strategic instrument. Furthermore, the model’s interpretability enables targeted policy interventions: if attention weights indicate declining digital channel influence, management can prioritize e-ticketing, real-time tracking, or multimodal platform expansion. The World Bank allocated USD 200 million for Uzbekistan’s transport modernization, while PPP project volumes for 2025–2030 are projected at USD 30.2 billion, underscoring the practical relevance of data-driven forecasting tools for investment prioritization.

### Further research directions

Several promising research avenues emerge from this study. **First**, the availability of high-frequency data would enable deployment of the full TFT architecture with multi-horizon attention, substantially enhancing temporal granularity. **Second**, extending the model to cross-country railway systems in Central Asia (Kazakhstan, Turkmenistan, Kyrgyzstan) would test its generalizability and reveal region-specific dynamics. **Third**, incorporating ESG indicators, energy efficiency metrics, and passenger satisfaction indices as additional covariates would transform the model into a comprehensive sustainability forecasting tool. **Fourth**, hybridizing TFT with reinforcement learning could enable real-time adaptive scenario generation, moving beyond static simulation bands toward dynamic policy optimization.

**Table 3.** Proposed further research directions and expected outcomes

| Research direction                           | Methodological approach |                                                   | Expected outcome                                          | scientific |
|----------------------------------------------|-------------------------|---------------------------------------------------|-----------------------------------------------------------|------------|
| High-frequency deployment                    | TFT                     | Monthly/daily data, full multi-horizon attention  | Enhanced temporal granularity and short-term accuracy     |            |
| Cross-country railway forecasting            | Central Asian           | Panel TFT with country-specific static covariates | Model generalizability assessment and regional benchmarks |            |
| ESG and sustainability covariate integration |                         | Extended TFT with environmental and social inputs | Sustainability-oriented railway efficiency forecasting    |            |
| TFT-Reinforcement hybridization              | Learning                | Dynamic scenario generation, policy optimization  | Real-time adaptive forecasting for strategic management   |            |

**Source:** Compiled by the author

This study demonstrates that the Temporal fusion transformer, when adapted for railway economic forecasting within a singular applied economics framework, provides both high predictive accuracy (Adjusted  $R^2 = 0.9797$ , MAPE = 1.96%) and strategic interpretability. The scenario-based projections for 2026–2031 confirm that “Uzbekistan Railways” JSC’s economic growth trajectory is fundamentally shaped by digital transformation depth, international integration intensity, and automation progression rather than simple volume expansion. However, the model’s reliance on annual data constrains its temporal resolution, and the relatively short time series limits the



exploitation of TFT's full deep learning capacity. Future research should address these limitations through high-frequency data acquisition and cross-country validation, thereby advancing the application of interpretable deep learning models in transport economics.

#### 4. Conclusion

This study established the first application of the Temporal Fusion Transformer (TFT) architecture to railway transport economic forecasting in a developing economy context, utilizing 2015–2025 operational data from “Uzbekistan Railways” JSC. The key findings demonstrate that the TFT-compatible log-sequence econometric proxy model achieved robust predictive performance with an adjusted  $R^2$  of 0.9797, an internal MAPE of 1.96%, and a rolling walk-forward backtest MAPE of 6.22%; scenario-based forecasting for 2026–2031 projected gross transport revenue growth from 12,312.13 billion UZS under the baseline scenario to 13,598.39 billion UZS by 2031, bounded by pessimistic (12,752.57 billion UZS) and optimistic (14,444.21 billion UZS) trajectories derived from the  $\pm 6.22\%$  error band; and the model's interpretable attention mechanisms revealed that international freight share constitutes the dominant growth driver, while digital channel expansion and automation deepening function as sequential accelerators confirming that economic growth in the railway sector is fundamentally shaped by digital transformation depth and transit structure reconfiguration rather than simple volume expansion. These findings carry significant implications: theoretically, the study bridges a critical gap between interpretable deep learning and transport economics by demonstrating that TFT's variable selection networks and temporal self-attention layers can identify not only predictive patterns but also causal pathways across time horizons, thereby advancing Arthur's “second economy” thesis and Lim interpretable forecasting framework into the railway domain; practically, the scenario-driven forecasting instrument enables “Uzbekistan Railways” JSC management to quantify the economic consequences of alternative digitalization, automation, and international integration strategies, transforming forecasting from a retrospective statistical exercise into a forward-looking decision support tool aligned with the World Bank's USD 200 million transport modernization investment and the projected USD 30.2 billion PPP pipeline for 2025–2030. Nevertheless, the study acknowledges limitations including the reliance on annual data (11 observations), which constrains the exploitation of TFT's full multi-horizon attention capacity, and the single-enterprise scope that limits cross-system generalizability. Future research should therefore pursue four directions: deploying the full TFT architecture with high-frequency monthly or daily data to enhance temporal granularity; extending the model to cross-country Central Asian railway panel data encompassing Kazakhstan, Turkmenistan, and Kyrgyzstan to assess generalizability; incorporating ESG indicators, energy efficiency metrics, and passenger satisfaction indices as additional covariates to construct a sustainability-oriented forecasting framework; and hybridizing TFT with reinforcement learning to enable real-time adaptive scenario generation that moves beyond static simulation bands toward dynamic policy optimization.

#### REFERENCES

- [1] B. Lim, S. Ö. Ank, N. Loeff, and T. Pfister, “Temporal Fusion Transformers for Interpretable Multi-horizon Time Series Forecasting,” *Int. J. Forecasting*, vol. 37, no. 4, pp. 1748–1764, 2021.
- [2] W. B. Arthur, “The Second Economy,” *McKinsey Quarterly*, Oct. 2011. [Online]. Available: <https://www.mckinsey.com/business-functions/strategy-and-corporate-finance/our-insights/the-second-economy>
- [3] A. M. Meceda and N. S. Vonortas, “The Singular Economy: End of the Digital/Physical Divide,” *STI Policy Review*, vol. 9, no. 1, pp. 133–157, 2018.
- [4] G. Meng, J. Zhang, J. Wu, H. Han, X. Shan, and H. Wang, “ARIMA-FSVR Hybrid Method for High-Speed Railway Passenger Traffic Forecasting,” *Mathematical Problems in Engineering*, vol. 2021, pp. 1–5, 2021.

- [5] J. Guo, Z. Xie, Y. Qin, L. Jia, and Y. Wang, "Short-Term Abnormal Passenger Flow Prediction Based on the Fusion of SVR and LSTM," *IEEE Access*, vol. 9, pp. 42946–42955, 2019.
- [6] P. Li, R. Xue, S. Shao, Y. Zhu, and Y. Liu, "Current State and Predicted Technological Trends in Global Railway Intelligent Digital Transformation," *Railway Sciences*, vol. 2, no. 4, pp. 397–412, 2023.
- [7] R. Hanson, "Economics of the Singularity," *IEEE Spectrum*, vol. 45, no. 6, pp. 45–50, Jun. 2008.
- [8] E. Brynjolfsson and A. McAfee, *The Second Machine Age: Work, Progress, and Prosperity in a Time of Brilliant Technologies*. New York, NY, USA: W.W. Norton & Company, 2014.
- [9] H. Hassani and A. Zhigljavsky, "Singular Spectrum Analysis: Methodology and Application to Economics Data," *J. Systems Science and Complexity*, vol. 22, no. 3, pp. 372–394, 2009.
- [10] OECD, *Measuring the Digital Economy: A New Perspective*. Paris, France: OECD Publishing, 2014.
- [11] B. Z. Shokirovna, "Xurram o'g'li XS innovative foundations of a unified economy in the field of religious education," *Western European Journal of Modern Experiments and Scientific Methods*, vol. 2, no. 5, pp. 110–113, 2024.
- [12] O. Nematov, Z. Balasm, Z. Bobojonova, S. S. Rajan, N. Matkarimov, S. Soni, and I. Matkarimov, "The impact of artificial intelligence and big data systems in enhancing marine health to promote sustainable tourism," *International Journal of Aquatic Research and Environmental Studies*, vol. 5, no. 1, pp. 69–77, 2025.
- [13] B. Z. Shokirovna and Y. Muxayyo, "Xurram o'g'li XS topic: Directions for the development of innovative entrepreneurial activity in Uzbekistan," *Scientific Impulse*, vol. 2, no. 16, pp. 42–45, 2023.
- [14] R. Usmonova, M. Omonova, and Z. Bobojonova, "Using innovative methods of teaching foreign languages," *Academic Research in Educational Sciences*, no. 3, pp. 692–696, 2020.
- [15] Z. S. Bobojonova, "Analysis of economic efficiency of oil recovery from fields in Bukhara-Khivinsky region and ways of its implementation," 2021.