

UDC 330.131.7:330.322.5
JEL: C63; D81; G32
DOI: <https://doi.org/10.32983/2222-4459-2026-7-472-487>

INTEGRATING MONTE CARLO SIMULATION AND FUZZY LOGIC INTO DCF VALUATION: FRAMEWORK FOR INCORPORATING GEOPOLITICAL RISK

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JEL: C63; D81; G32

Stashchuk D. M., Aleksin G. O. Integrating Monte Carlo Simulation and Fuzzy Logic into DCF Valuation: Framework for Incorporating Geopolitical Risk

This study aims to develop and empirically validate a corporate valuation framework for conflict-affected environments, where deterministic Discounted Cash Flow (DCF) models do not adequately represent stochastic variability or qualitative ambiguity. The research examines how DCF valuation, Monte Carlo simulation, and fuzzy logic can be combined, how geopolitical conditions can be translated into a quantitative risk-premium adjustment, and how this integration changes the enterprise valuation and downside-risk profile of Ukrainian Railways. The proposed model employs a multi-layer methodology. A deterministic five-year DCF establishes the benchmark enterprise value; a rule-based fuzzy inference system converts expert assessments of territorial control stability, infrastructure damage, economic recovery, and regulatory and political stability into an additive geopolitical risk premium; and a 10.000-iteration Monte Carlo simulation models uncertainty in the weighted average cost of capital and terminal growth rate. The framework combines possibilistic treatment of qualitative ambiguity with probabilistic analysis of financial variability. Applied to Ukrainian Railways, the fuzzy system yields an 8.84 percentage-point geopolitical risk premium. The uncertainty-adjusted simulation yields a mean enterprise value of USD 947 million and a 95% downside floor of USD 601 million, compared with the deterministic estimate of USD 1.551 million. The results identify WACC as the principal channel through which geopolitical and macro-financial uncertainty reduces enterprise value. The framework offers investors, analysts, creditors, managers, and policymakers a transparent basis for valuation, restructuring, stress testing, and evaluating policies that improve institutional stability and infrastructure resilience. Its relevance lies in making the economic cost of geopolitical instability visible for a strategic provider of transport, evacuation, humanitarian logistics, and postwar integration. The study's originality is a coherent, replicable linkage of fuzzy geopolitical assessment, a quantitative discount-rate adjustment, and stochastic DCF outcomes. Generalizability is limited by single-case, expert-based rules and fixed cash flows; future research should calibrate fuzzy parameters empirically, allow geopolitical conditions and cash flows to evolve dynamically, and validate the method across sectors and countries.

Keywords: discounted cash flow (DCF); Monte Carlo simulation; fuzzy logic; valuation; geopolitical risk.

Fig.: 1. **Tabl.:** 11. **Formulae:** 9. **Bibl.:** 23.

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УДК 330.131.7:330.322.5
JEL: C63; D81; G32

Сташук Д. М., Алексін Г. О. Інтеграція моделювання Монте-Карло та нечіткої логіки в оцінку методом DCF: рамка для врахування геополітичних ризиків

Метою дослідження є розробка та емпірична перевірка оцінки компанії для середовищ, уражених конфліктом, де детерміновані моделі дисконтованих грошових потоків (DCF) недостатньо відображають стохастичну мінливість або невизначеність. Дослідження демонструє, як оцінка DCF, моделювання Монте-Карло та нечітка логіка можуть поєднуватися, як геополітичні умови можуть бути перетворені на кількісне коригування ризику та премії, а також як ця інтеграція змінює оцінку підприємств і профіль ризиків АТ «Укрзалізниця». Пропонована модель використовує багаторівневу методологію. Детермінований п'ятирічний DCF встановлює базову вартість підприємства; система нечіткої логіки перетворює експертні оцінки стабільності територіального контролю, пошкодження інфраструктури, економічного відновлення, а також регуляторної та політичної стабільності на додаткову геополітичну премію за ризик; симуляція Монте-Карло з 10 000 ітерацій моделює невизначеність у WACC і темпах зростання. Ця рамка поєднує оцінку невизначеності з ймовірнісним аналізом фінансової волатильності. Застосована до АТ «Укрзалізниця», ця система дає премію за геополітичний ризик у розмірі 8,84 відсоткового пункту. Симуляція з урахуванням невизначеності дає середню вартість підприємства 947 млн доларів США та нижню межу 601 млн доларів США за 95% ймовірності, порівняно з базовою оцінкою в 1 551 млн доларів США. Результати визначають WACC як основний канал, через який геополітична та макророзривна невизначеність знижує вартість компанії. Ця рамка надає інвесторам, аналітикам, кредиторам, менеджерам і політикам прозору основу для оцінки вартості, реструктуризації, стрес-тестування та оцінювання політик, що підвищують стабільність інституцій і стійкість інфраструктури. Її значущість полягає в тому, щоб зробити економічну ціну геополітичної нестабільності видимою для галузей транспорту, евакуації, гуманітарної логістики та післявоєнної інтеграції. Оригінальність дослідження полягає в послідовному, відтворюваному зв'язку між нечіткою геополітичною оцінкою, кількісною корекцією ставки дисконтування та стохастичними результатами DCF. Дослідження обмежене експертними судженнями та фіксованими грошовими потоками. Майбутні дослідження можуть емпірично калібрувати нечіткі параметри, що дозволить геополітичним умовам і грошовим потокам динамічно змінюватися під час моделювання, а також валідувати метод у різних секторах і країнах.

Ключові слова: дисконтований грошовий потік (DCF); симуляція Монте-Карло; нечітка логіка; оцінка; геополітичний ризик.

Рис.: 1. **Табл.:** 11. **Формул:** 9. **Бібл.:** 23.

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The Discounted Cash Flow (DCF) framework is a central method in financial valuation and is widely used to assess projects, assets, and firms. It is based on the principle that an asset's value equals the present value of its expected future cash flows. In this way, DCF provides an estimate of intrinsic value grounded in the entity's anticipated cash-generating capacity.

While robust in its theoretical underpinnings, the traditional DCF framework faces critical limitations when confronted with the unpredictable nature of market conditions. These limitations are particularly pronounced in environments characterized by high volatility in social, economic, and geopolitical landscapes. The conventional DCF framework often fails to adequately capture the nuances and uncertainties inherent in these factors, leading to valuation inaccuracies.

Integrating Monte Carlo simulation into the DCF framework provides a way to address these limitations. Monte Carlo simulation is a computational method that models the distribution of possible outcomes in processes subject to random variation. Applied to valuation, it allows the analysis to incorporate a range of plausible future scenarios rather than relying solely on fixed assumptions, thereby extending the traditional deterministic structure of the DCF framework.

Further enhancing this integration, fuzzy logic provides a powerful tool for handling qualitative variables and uncertainties that are difficult to quantify. Fuzzy logic enables reasoning with imprecise and ambiguous information, making it particularly useful in financial valuation under uncertainty. By incorporating fuzzy sets and rules, the model can capture the impact of qualitative factors such as geopolitical risks, ESG factors, and market sentiment, which traditional DCF and Monte Carlo methods may not fully capture.

LITERATURE REVIEW

Discounted Cash Flow (DCF) constitutes the theoretical cornerstone of corporate valuation, grounded in the principle that the value of an asset equals the present value of its expected cash flow. Foundational contributions by F. Modigliani and M. Miller established the central role of the cost of capital in determining enterprise value [19]. At the

same time, subsequent developments formalized DCF as a dominant valuation framework in both academic and professional practice. Later works by A. Damodaran (2012) [7], T. Copeland et al. (2020) [6], and R. Brealey et al. (2019) [3] further refined the methodology by detailing its application across asset classes and market environments. Despite its strong theoretical foundations, the traditional DCF framework relies heavily on deterministic assumptions regarding key inputs such as projected cash flows, growth rates, and discount rates. Even minor variations in these inputs can lead to substantial differences in valuation outcomes. Empirical and applied studies further highlight that such assumptions are particularly fragile in volatile environments characterized by macroeconomic instability and structural uncertainty.

Recent research reinforces these limitations. For example, S. Teker (2020) demonstrates that DCF models are especially sensitive in emerging markets, where inflation, interest rates, and risk premiums are unstable [21]. Moreover, H. Bessembinder (2020) shows that the convexity embedded in discounting and compounding mechanisms may introduce systematic upward bias in valuation estimates [2]. Collectively, these findings underscore the need for more flexible valuation frameworks that can incorporate both variability and structural uncertainty.

To address the limitations of deterministic valuation, the literature has increasingly adopted probabilistic modeling techniques, most notably Monte Carlo simulation. Early work by D. B. Hertz (1964) introduced simulation methods into capital budgeting, demonstrating their ability to model uncertainty by assigning probability distributions to key variables [12]. Later contributions by P. Glasserman (2003) and J. Hull (2018) extended these techniques to financial engineering and derivatives valuation, solidifying their methodological foundation [11; 13].

Recent empirical studies confirm the growing relevance of Monte Carlo simulation in valuation practice. Z. Hussain (2019) demonstrates the usefulness of simulation in forecasting project cash flows under uncertainty [14], while R. Drissi (2023) finds that dynamic valuation frameworks based on distributions provide more reliable estimates than static models [9].

However, despite these advantages, Monte Carlo simulation remains inherently dependent on predefined probability distributions. As emphasized by L. Clewlow and C. Strickland (1998), the accuracy of simulation outcomes is highly sensitive to distributional assumptions. This limitation becomes particularly critical when dealing with uncertainty that is not purely stochastic but also qualitative or ambiguous [5]. Consequently, while Monte Carlo methods enhance the treatment of quantitative uncertainty, they do not fully capture the broader spectrum of risks relevant to real-world valuation.

Fuzzy logic, introduced by L. A. Zadeh (1965), provides a complementary framework for handling imprecision and ambiguity in complex systems [23]. Unlike classical binary logic, fuzzy logic allows variables to take on degrees of membership, enabling the formal representation of qualitative concepts such as “high risk” or “moderate stability.” Foundational work by G. J. Klir and B. Yuan (1995) further developed the theoretical basis for applying fuzzy sets across various domains, including finance [15].

In financial applications, fuzzy logic has been increasingly used to incorporate qualitative factors into valuation and forecasting models. For instance, G. S. Milanesi (2019, 2020) applies fuzzy logic to model macroeconomic uncertainty in emerging markets, demonstrating its effectiveness in capturing inflation and exchange rate volatility [17; 18]. T. Korol (2018) and A. M. Duarte Júnior and H. G. de Albuquerque e Silva (2018) further demonstrate the usefulness of fuzzy approaches in financial ratio forecasting and equity valuation, particularly when dealing with subjective or imprecise inputs [16; 10].

Despite these contributions, existing applications of fuzzy logic in finance remain limited in scope. Most studies focus on specific valuation or decision-making aspects rather than integrating fuzzy logic into a comprehensive valuation framework. Moreover, as noted in several empirical studies, fuzzy models are typically developed independently of probabilistic approaches, resulting in frameworks that capture qualitative ambiguity but fail to incorporate stochastic variability.

Recognizing the complementary strengths of probabilistic and fuzzy methodologies, recent research has begun to explore hybrid approaches that combine Monte Carlo simulation with fuzzy logic. These models aim to address both stochastic uncertainty and qualitative ambiguity by integrating probability and possibility theories.

For example, F. D. Wicaksono et al. (2020) propose a hybrid fuzzy – Monte Carlo framework that improves decision-making consistency under uncer-

tainty [22]. Similarly, M. A. Alzarrad (2020) develops a fuzzy Monte Carlo simulation (FMCS) model for resource optimization, demonstrating improved accuracy and efficiency compared to traditional approaches [1]. K. A. Chrysafis and B. K. Papadopoulos (2020) introduce a fuzzy-possibilistic NPV framework that accounts for uncertainty in project appraisal, further illustrating the potential of hybrid methodologies [4].

While these studies demonstrate promising results, their applications remain fragmented and context specific. Most hybrid models are developed for project evaluation, engineering decision-making, or multi-criteria analysis, rather than for corporate valuation within a DCF framework. Furthermore, the integration of these approaches is often ad hoc, lacking a standardized methodology that systematically links qualitative inputs, probabilistic modeling, and valuation outputs.

Importantly, the application of such hybrid models to geopolitical risk remains largely underexplored. Although R. Moro-Visconti (2021) highlights the importance of incorporating ESG factors into valuation [20], and R. Delao and S. Myers (2021) emphasize the role of subjective expectations in asset pricing [8], there is limited research on how to formally integrate geopolitical risks – particularly in conflict-affected environments – into valuation models. This represents a critical gap in the literature.

The review of both classical and recent literature reveals a clear gap in the field of corporate valuation. Traditional DCF models, established by F. Modigliani and M. H. Miller and further developed by A. Damodaran (2012) and R. A. Brealey et al. (2020), provide a strong theoretical foundation but are limited by their deterministic nature [19; 7; 3]. Probabilistic approaches, particularly Monte Carlo simulation, enhance the treatment of quantitative uncertainty but remain constrained by their reliance on predefined distributions [12; 11]. Conversely, fuzzy logic approaches enable the modeling of qualitative ambiguity but are typically applied in isolation [23; 15; 18].

Recent hybrid approaches by F. D. Wicaksono et al. and M. Alzarrad demonstrate the potential of integrating these methodologies [22; 1]; however, existing applications remain fragmented and lack a unified conceptual framework. There is a notable absence of integrated valuation models that simultaneously capture stochastic variability and qualitative ambiguity within a DCF setting. This gap is especially critical in the context of geopolitical risk, where uncertainty is multidimensional, dynamic, and difficult to quantify.

This study addresses this gap by developing a unified valuation framework that integrates the DCF model, Monte Carlo simulation, and fuzzy logic. The

framework enables the systematic incorporation of geopolitical risk through structured fuzzy variables while simultaneously modeling quantitative uncertainty using probabilistic techniques. Applied to a case of a company operating in a conflict-affected environment, the framework illustrates how these methods can be combined within a corporate valuation setting.

AIM AND RESEARCH QUESTIONS

The primary aim of this study is to propose and validate a refined DCF framework that seamlessly integrates Monte Carlo simulation and fuzzy logic. This integration aims to enhance the accuracy and reliability of valuation under uncertain market conditions by considering both quantitative and qualitative uncertainties. This paper contributes to the existing body of knowledge by bridging methodological gaps and offering a comprehensive approach to corporate valuation by answering such research questions:

- a) How can Discounted Cash Flow valuation, Monte Carlo simulation, and fuzzy logic be integrated into a coherent framework that captures both stochastic variability and qualitative ambiguity?
- b) How can qualitative geopolitical factors be translated systematically into a quantitative risk-premium adjustment to the discount rate?
- c) To what extent does the integrated uncertainty-adjusted framework alter the enterprise valuation and downside-risk profile of Ukrainian Railways relative to a deterministic DCF estimate?

The study is relevant for investors, financial analysts, and other decision-makers because it develops a valuation framework that accounts for uncertainty more systematically than conventional deterministic approaches.

METHODOLOGY

This section outlines the methodological framework for integrating Monte Carlo simulation and fuzzy logic into the Discounted Cash Flow (DCF) model. The framework is designed to support corporate valuation under elevated uncertainty by incorporating both quantitative and qualitative determinants of valuation outcomes through a defined sequence of analytical steps.

Step 1: Establishing the Deterministic Baseline

Before incorporating fuzzy logic and stochastic simulation, the framework first establishes a baseline valuation. This step serves as a reference point for the analysis by representing enterprise value under conventional business-as-usual assumptions. The baseline valuation subsequently enables the assessment of the extent to which geopolitical volatility affects enterprise value.

The analysis begins with the construction of a standard Free Cash Flow (FCF) model. This involves projecting the enterprise's operating performance based on historical trends and management targets, under the assumption of a relatively stable external environment.

This process yields a five-year forecast of Free Cash Flow (FCF) representing the enterprise's expected performance in the absence of major external shocks, including conflict-related escalation. Beyond the five-year forecast horizon, free cash flow is assumed to converge to a stable long-term growth rate, reflecting a mature stage of enterprise development characterized by sustainable, though slower, expansion consistent with broader market conditions.

At this stage, the weighted average cost of capital (WACC) is estimated using conventional market-based inputs, including the risk-free rate and historical equity beta. This static WACC specification captures only systematic market risk, as reflected in beta, and does not incorporate idiosyncratic or non-linear risks associated with conflict-affected environments, including abrupt regulatory intervention or physical asset destruction.

This deterministic calculation produces a single valuation estimate. Although this estimate may be upwardly biased under conflict conditions, it serves an important benchmarking function within the framework. Specifically, it provides a reference valuation against which the effects of fuzzy-logic adjustments and Monte Carlo simulation can subsequently be assessed to derive a risk-adjusted enterprise value.

Enterprise value is obtained by summing the present values of forecast cash flows for years 1 to 5 and the present value of the terminal value. This estimate reflects the enterprise's intrinsic value under the assumed cash flow projections and a long-term, stable growth path. As such, it serves as a benchmark for investment analysis and for comparison with observed market prices and alternative valuation measures.

Step 2: Diagnosing Key Value Drivers

Following the establishment of the baseline valuation, the second phase focuses on identifying the variables most likely to contribute to valuation volatility under conflict conditions. In complex financial models, input variables differ substantially in their influence on valuation outcomes. Accordingly, the framework emphasizes identifying key value drivers, defined as inputs with the greatest material effect on enterprise value. These drivers are subsequently classified into two categories within the hybrid valuation framework.

These variables represent internal financial determinants that directly influence cash-flow generation. Under conflict conditions, disruptions to conventional operating and market relationships may increase the

volatility of these variables and, consequently, their effect on valuation outcomes. The identification of key value drivers is informed by a sensitivity analysis that assesses each variable's relative contribution to the overall enterprise valuation. This procedure supports the inclusion of variables with the greatest explanatory relevance in the stochastic modeling framework, thereby enhancing model parsimony and computational efficiency.

The variables represent external environmental factors that are typically excluded from standard DCF models because of the difficulty of assigning them precise quantitative measures. Within the present framework, however, they are treated as the principal determinants of geopolitical risk premium.

The framework identifies macro-level threats that define the operating environment, including geopolitical instability, regulatory predictability, and supply chain fragility. Because these factors cannot be represented adequately by single-point numerical estimates, they are modeled as linguistic variables. These variables are subsequently processed through the fuzzy-logic system (Step 4) to derive the appropriate adjustment to the discount rate.

By explicitly distinguishing between these two categories, the framework captures both the *financial effects* of conflict-affected environments through cash-flow projections and the *strategic risk* of the operating environment through the discount rate.

Step 3: Calibrating the Valuation Structure

With the operational forecast (Step 1) and key value drivers (Step 2) established, the third phase specifies the mathematical structure for incorporating these inputs into the valuation model. Although the numerical values assigned to growth and risk parameters vary across simulation iterations, the underlying structural relationships governing valuation remain fixed and are derived from established financial theory.

The purpose of this stage is to convert uncertain future cash flows into their present values. The weighted average cost of capital (WACC) is applied as the discount rate (see Formula 1).

$$WACC = We \cdot Re + Wd \cdot Rd \cdot (1 - t), \quad (1)$$

where: We – weight of Equity; Re – cost of equity; Wd – weight of Debt; Rd – cost of Debt; t – tax rate.

Under conflict conditions, the relative value of near-term cash flows increases because future cash flows are exposed to elevated risks, including asset destruction, expropriation, and currency instability. The model discounts projected cash flows over time to reflect the heightened risk associated with more distant periods.

An important component of this stage is the estimation of the terminal value, the enterprise's value beyond the initial five-year forecast horizon. In conventional valuation settings, terminal value is often

estimated under a perpetuity assumption. In conflict-affected environments, however, this assumption may be insufficiently conservative. Accordingly, the terminal value specification is made highly sensitive to the exit yield and long-term growth assumptions to reduce the risk of overstating enterprise value through an implausibly rapid normalization of post-conflict conditions.

This stage combines the discounted short-term cash flows and the discounted terminal value to derive a single estimate of enterprise value (EV; see Formula 2).

$$EV = \sum_{t=1}^T \frac{FCF_t}{(1+WACC)^t} + \frac{TV}{(1+WACC)^T}, \quad (2)$$

where: FCF_t – free cash flow in period t ; $WACC$ – weighted average cost of capital; TV – terminal value; T – number of periods.

Before conducting the stochastic simulation (Steps 4–6), this static calculation is performed to generate a benchmark valuation. This benchmark subsequently serves as the reference point against which the distribution of simulated valuation outcomes is compared to assess the valuation effect of conflict-related risk.

Step 4: Quantifying Qualitative Geopolitical Risk

This stage formalizes the translation of qualitative expert assessments into quantitative inputs suitable for integration within the DCF framework. Conventional valuation models are limited in their ability to represent linguistic ambiguity, such as assessments of elevated conflict escalation risk or moderate supply-chain disruption. To address this limitation, the framework employs a fuzzy-inference system that converts imprecise qualitative information into operational valuation parameters.

Within the hybrid framework, qualitative exogenous risks are processed by the fuzzy inference system to generate a risk premium. This premium is then used to adjust the discount rate within the Monte Carlo simulation, which simultaneously evaluates stochastic financial variables and produces a probability distribution of enterprise value.

Rather than assigning precise numerical percentages to abstract external risks, the framework represents key geopolitical factors, including Geopolitical Instability and Regulatory Uncertainty, through linguistic categories such as Low, Medium, and High. In contrast to binary logic, which treats a risk condition as either present or absent, the framework allows simultaneous partial membership across categories. A given situation may therefore exhibit characteristics associated primarily with a medium-risk state while also displaying features consistent with a high-risk state. This approach preserves gradation in expert as-

assessments that would otherwise be lost under discrete scenario classification.

A central component of the framework is a rule-based system derived from expert judgment. This system consists of a set of conditional If – Then statements that specify how external shocks are translated into adjustments of financial risk parameters. *Example Rule:* "IF Geopolitical Instability is High AND Market Liquidity is Low, THEN the geopolitical risk premium should be Very High". This rule promotes consistency in the treatment of qualitative geopolitical conditions and reduces reliance on ad hoc adjustments to the discount rate.

After the current environment has been evaluated against the rule base, the system must generate a single numerical output that can be incorporated into the financial model. For this purpose, the framework employs the Centroid Method (Center of Gravity). This method determines the representative value of the aggregated output membership function by weighting the contribution of all activated rules. As a result, the final output reflects a weighted average of the relevant risk states rather than selecting a single extreme scenario. The resulting defuzzified value is incorporated directly into the Discounted Cash Flow model as an adjustment to WACC, thereby linking the discount rate to a structured qualitative assessment of geopolitical risk.

Formally, the fuzzy inference system's output is incorporated into the valuation model as an additive adjustment to the discount rate (see Formula 3).

$$\begin{aligned} \text{Adjusted WACC adjusted} = \\ = \text{Baseline WACC} + \text{RP fuzzy}, \end{aligned} \quad (3)$$

where: *RP fuzzy* denotes the risk premium derived from the fuzzy-logic system.

This formulation ensures that qualitative geopolitical factors are systematically translated into quantitative valuation adjustments.

Step 5: Defining the Shape of Uncertainty

Once the fuzzy inference system has generated the relevant risk premiums, the next stage addresses the stochastic variability of the quantitative inputs. In a deterministic DCF framework, parameters such as revenue growth may be represented by single-point estimates; however, under conflict conditions, such a specification may understate the degree of uncertainty. Accordingly, key financial drivers are modeled as stochastic variables defined by probability distributions.

To reflect differences in the underlying nature of uncertainty across model inputs, the framework employs two distributional forms, each corresponding to a distinct category of valuation drivers. For financial inputs that fluctuate around a relatively stable central tendency, such as the WACC risk premium, the frame-

work applies a Normal (Gaussian) distribution. Even in volatile markets, interest rates and expected returns often remain concentrated around a mean value, with the probability of extreme deviations declining as the distance from the mean increases. Parameterization through a mean and a standard deviation provides a tractable representation of market variability while preserving the assumption of bounded dispersion around an equilibrium tendency.

For variables highly sensitive to exogenous shocks, particularly the terminal growth rate, the framework uses a uniform distribution. In conflict-affected environments, conventional cyclical patterns may not provide a reliable basis for identifying a dominant expected outcome. Under such conditions, any realization within a specified interval may be considered comparably plausible, provided the conflict's trajectory and intensity are taken into account. The uniform distribution is therefore used to represent uncertainty without imposing a central tendency that may lack empirical justification.

By assigning distinct distributional forms to valuation inputs, the model captures heterogeneity in the structure of uncertainty across variables and enables the Monte Carlo simulation to evaluate a broad range of plausible outcomes rather than a single deterministic trajectory. Distributional assumptions are specified based on historical patterns, industry benchmarks, and expert judgment. In this framework, revenue growth and terminal growth are modeled using uniform distributions to reflect the absence of a clearly dominant outcome under elevated uncertainty. In contrast, financial variables such as the cost of equity and the cost of debt are modeled using normal distributions because they tend to fluctuate around a central value.

The parameters of these distributions are calibrated using historical financial data, industry benchmarks, forward-looking expectations, and expert judgment to ensure that the stochastic inputs remain empirically grounded and contextually relevant to the enterprise's operating environment.

Step 6: Monte Carlo Simulation

The final stage of the framework integrates the qualitative risk premiums derived in Step 4 with the stochastic input distributions specified in Step 5 within a unified Monte Carlo simulation. Whereas a conventional DCF model yields a single-point valuation, the simulation generates a distribution of potential valuation outcomes that reflects the joint effect of uncertainty across the modeled inputs.

The Monte Carlo valuation model is executed over 10,000 independent iterations to ensure statistical stability of the simulated output distribution. This scale allows the analysis to capture both central ten-

dencies and tail outcomes, which are relevant for valuation under elevated uncertainty. In each iteration, the model draws values for the relevant stochastic inputs from the probability distributions specified in Step 5 and incorporates the fuzzy-logic risk premium from Step 4 into the discount rate. These sampled inputs are then used to calculate a corresponding enterprise value within the DCF framework, so that each iteration represents a distinct valuation scenario.

Rather than producing a single deterministic valuation, the simulation yields an empirical distribution of enterprise values. This distribution supports the assessment of the concentration of outcomes, downside exposure relative to specified benchmarks, and the likelihood of outcomes consistent with returns above the cost of capital. By aggregating many iterations, the simulation makes low-probability but economically significant outcomes observable and thereby extends the valuation exercise beyond point estimation to structured risk assessment under uncertainty.

The simulation is implemented in Microsoft Excel using data table functionality to execute many iterations efficiently. Random sampling is performed with built-in functions, including RAND() for uniform draws and NORM.INV(RAND()) for normally distributed variables. This implementation supports transparency, reproducibility, and practical applicability.

Step 7: Interpretation of Simulation Results

The final phase of the framework interprets the simulation's statistical output to support valuation and decision-making. The simulated results are examined through three complementary perspectives that characterize the enterprise's risk-adjusted valuation profile under conflict conditions.

Rather than relying exclusively on the mean valuation estimate, which may be sensitive to extreme observations, the analysis emphasizes the 90% confidence interval. This interval is obtained by excluding the lower and upper 5% tails of the simulated valuation distribution. The resulting central range represents the set of values within which enterprise value is most likely to lie, conditional on the modeled conflict-related risks. If the observed market price lies below this interval, the asset may be interpreted as undervalued relative to the simulated distribution of risk-adjusted intrinsic value.

Conventional valuation models provide point estimates but do not directly quantify downside exposure. Accordingly, this stage introduces the probability of economic loss as an explicit risk metric. The probability of economic loss is calculated as the proportion of simulation iterations in which the estimated intrinsic value falls below a predefined benchmark, such as market value or book value. This metric provides a direct probabilistic measure of downside risk

and complements conventional valuation outputs by incorporating the likelihood of adverse scenarios.

For example, an estimated 35% probability of loss indicates that 35% of simulated outcomes fall below the selected benchmark. This measure enables decision-makers to evaluate valuation outcomes against their respective risk tolerances and investment mandates. The mean valuation from the hybrid simulation is compared with the deterministic baseline valuation from Step 1 to isolate the valuation effects of qualitative geopolitical risk and stochastic shocks. This comparison distinguishes the enterprise's underlying operational value from the impact of the external risk environment, thereby supporting a more rigorous interpretation of market pricing under conflict conditions.

EMPIRICAL RESULTS

Joint Stock Company Ukrainian Railways (UZ – Ukrzaliznytsia) provides an appropriate empirical setting for examining corporate valuation under extreme geopolitical uncertainty. As Ukraine's principal railway operator and a strategic state-owned infrastructure enterprise, it combines the characteristics of a natural monopoly with those of a conflict-affected provider of essential transport and logistics services. Following its corporatization in 2014, UZ continued to operate under a cross-subsidization model in which profitable freight transportation offset persistent losses in passenger services.

The full-scale invasion of Ukraine in 2022 fundamentally altered the company's operating environment. UZ became a critical component of national resilience, facilitating evacuation, military logistics, and humanitarian transport. However, this shift was accompanied by substantial economic losses, including the destruction of infrastructure, a collapse in freight volumes, and rising operational costs. By 2026, the company entered a state of selective default, reflecting severe financial distress and constrained debt-servicing capacity.

As a benchmark, a standard DCF valuation is constructed using projected Free Cash Flows (FCF) over a five-year horizon (2026–2030) and a terminal value based on long-term growth assumptions. The weighted average cost of capital (WACC) for a conflict-affected infrastructure monopoly requires accounting for extreme country risk while using a mature "target" capital structure rather than current distressed balance-sheet values. All the components are presented in *Tbl. 1* and *Tbl. 2*.

The cost of equity is calculated using the CAPM (Capital Asset Pricing Model), where CRP is added to the market risk component (see Formula 4).

$$Re = Rf + \beta \cdot ERP + CRP, \quad (4)$$

where: Rf – Risk-Free Rate; β – Beta Coefficient; ERP – Equity Risk Premium; CRP – Country Risk Premium.

$$Re = 3.95\% + 1.6 \cdot 4.46\% + 15.54\% = 26.63\%.$$

The cost of debt was estimated based on the data in *Tbl. 2*.

Table 1

Cost of Equity (Re)

Parameter	Value	Notes
Risk-Free Rate (Rf)	3.95%	10-year US Treasury rate as of Jan 2026 (4.18%) adjusted for US default risk (0.23%)
Equity Risk Premium (ERP)	4.46%	Mature market (US) implied ERP as of 2026
Beta Coefficient	1.60	Conflict-adjusted levered beta reflects high operational leverage and infrastructure risk
Country Risk Premium (CRP)	15.54%	For Ukraine

Source: developed by the authors.

Table 2

Cost of Debt (Rd)

Benchmark	Corporate Spread	Pre-Tax Rd	Marginal Tax Rate (Tc)	After-Tax Cost of Debt
Ukraine 1-year government bond yield of 16.35% (Dec. 2025)	A distressed spread of 1,200 bps reflects the current SD status	~28.0%	18%	28% (1 – 0.18) = 22.96%

Source: developed by the authors.

To avoid the distortions caused by conflict-related financial distress, we apply a target-market capital structure for the global railroad industry. Market benchmarks for rail transportation show a debt-to-equity (D/E) ratio of approximately 1.14. This implies a target capital structure of 46.7% Equity and 53.3% Debt. WACC is calculated as Formula 1.

$$WACC = 0.467 \cdot 26.63\% + 0.533 \cdot 28\% \cdot (1 - 0.18) = 24.68\%.$$

The transition from a current company's liquidity gap to positive Free Cash Flow is driven by five structural shifts:

1. Year 2027 – Cargo Volume Recovery. Post-ceasefire stabilization will enable restoration of the "metallurgical corridor", with freight volumes expected to gradually return to approximately 75% of 2021 levels (about 235 million tons) by 2029, up from 161 million tons in 2025. Normalized Black Sea port operations and the reopening of key industrial facilities in eastern Ukraine drive this improvement. Initial efforts will focus on grid repairs and reducing liquidity gaps, setting the foundation for renewed operational infrastructure and financial stability.

2. Year 2027 – EU Gauge Integration and Market Access. By 2027, completion of European-gauge (1.435 mm) tracks to Lviv and Kovel will eliminate border-related logistical delays and "break-of-gauge" costs, facilitating high-margin transit and supporting the resurgence of the metallurgical sector. This infrastructure upgrade is a key milestone for cross-border logistics and broader economic recovery.

3. Year 2028 – Tariff Adjustment and Revenue Stabilization. In 2028, full indexation of cargo tariffs is anticipated, following UZ's proposal to increase freight tariffs by 41.5% in 2026 to reflect producer price growth since 2022. The adoption of a transparent indexation model is essential for EU integration and is expected to enhance revenue stability, supporting the normalization of export flows and market dynamics.

4. Year 2029 – Operational and Market Reforms. By 2029, the implementation of EU Directive 2012/34/EU will result in the vertical separation of Ukrainian Railways into independent infrastructure and carrier units within three years post-martial law. This reform will introduce state co-financing mechanisms for passenger transit, ending the drain on cargo profits from loss-making passenger services, and supporting competitive market structures aligned with European standards.

5. Year 2030 – Sustained Integration and Efficiency. By 2030, the sector will reach a steady state of integration, consolidating efficiency gains from the "Build Back Better" initiative. These improvements will foster long-term resilience and sustainable operations across Ukraine's transport and logistics infrastructure.

The impact of all listed events will determine the free cash flow (Tbl. 3).

Using the baseline WACC of 24.68% and the explicit ceasefire forecast, we estimate the intrinsic enterprise value (EV).

Step 1: Present Value Calculation. The present value of the projected free cash flows equals USD 503 million (Tbl. 4).

Table 3

FCF Forecast, USD Million

Metric	2026	2027	2028	2029	2030	Total
Free Cash Flow Forecast	-269	95	366	570	702	1.465

Source: developed by the authors.

Table 4

DCF Calculation, USD Million

Metric	2026	2027	2028	2029	2030	Total
DCF	-216	61	189	236	233	503

Source: developed by the authors.

Step 2: Terminal Value (TV) Calculation. Assuming a terminal growth rate (g) of 2%, reflecting EU convergence, the terminal value is calculated by Formula 5, and its present value is calculated by Formula 6.

$$TV = FCF(5) \cdot (1 + g) / (WACC - g), \quad (5)$$

where: $FCF(5)$ – free cash flow in period 5; g – growth rate; $WACC$ – weighted average cost of capital.

$$TV = 702 \cdot (1 + 0.02) / (0.2468 - 0.02) = \\ = \text{USD } 3.157 \text{ million}$$

$$PV TV = TV / (1 + WACC)^5, \quad (6)$$

where: TV – terminal value; $WACC$ – weighted average cost of capital.

$$PV TV = 3,157 / (1 + 0.2468)^5 = \text{USD } 1,048 \text{ million.}$$

Step 3: Enterprise Value. The Enterprise Value is the sum of the discounted cash flow and the discounted terminal value (see Formula 7).

$$EV = PV FCF + PV TV, \quad (7)$$

where: $PV FCF$ – present value of free cash flow; $PV TV$ – present value of terminal value.

$$EV = 503 + 1.048 = \text{USD } 1.551 \text{ million.}$$

The valuation demonstrates that under a target capital structure and a successful ceasefire-driven recovery, Ukrainian Railways has an enterprise value of USD 1.551 million. This reflects the enterprise's capacity to return to profitability through EU gauge integration, tariff indexation, and the vertical separation of passenger and freight segments.

Despite the company's selective default status, the transition to the 1.435 mm gauge and the institutional requirements associated with EU accession provide a basis for medium-term free cash flow recovery. The realization of this trajectory, however, remains contingent on stabilization of the security environment. From a strategic perspective, the railway is likely to remain an important component of Ukraine's post-conflict economic integration with the European single market.

Qualitative uncertainty is incorporated into the valuation framework through fuzzy logic. The fuzzy inference system's output is added to the model as an additional risk premium that adjusts the discount rate. Geopolitical risk is modeled using four key dimensions with three possible states (see *Tbl. 5*).

Each scored 0–100 by expert judgment/analyst assessment.

The objective of the Rule Base is to convert four qualitative geopolitical inputs into an additional risk premium (see Formula 8).

$$RP_{fuzzy} \in \{Low, Medium, High, Very High\}. \quad (8)$$

Each rule is: IF [conditions] → THEN [risk level]. See examples in *Tbl. 6*.

We define 12 rules (scenarios) combining each of the four geopolitical factors (see *Appendix 1*). Each geopolitical factor is represented by a normalized score on a 0–100 scale derived from expert judgment and observable indicators. These scores are mapped to fuzzy membership functions (see *Appendix 2*) to determine the degree to which each variable belongs to predefined linguistic categories, such as low, medium, and high. This specification provides a structured basis for incorporating qualitative assessments into the fuzzy inference system.

Within the inference stage, multiple rules may be activated simultaneously, with each rule contributing an activation strength on the interval from 0 to 1. These activation levels are then aggregated to construct the fuzzy output that represents the implied geopolitical risk premium (see *Tbl. 7*).

Additional rules were evaluated but produced negligible activation levels and were therefore omitted for clarity.

Output Membership Levels. At this stage, each rule is assigned to its corresponding risk-premium category based on the premium centers from *Tbl. 8*.

The fuzzy output is then transformed into a single scalar estimate using the centroid (center-of-grav-

Table 5

Fuzzy input variables

Factor	States	Description	Impact
Territorial Control Stability (TCS)	Low, Medium, High	Ability of Ukraine to maintain/recover control over relevant operating regions	Rail corridors and occupied/liberated zones directly affect network utility
Infrastructure Damage Risk (IDR)	Low, Moderate, Severe	Probability/severity of rail track, bridges, stations, and rolling stock damage	Destroyed bridges/lines materially impair operations and capex needs
Economic Recovery Outlook (ERO)	Weak, Moderate, Strong	Expected pace of GDP recovery, freight demand, and industrial restart	Freight volumes are strongly tied to metallurgy, agriculture, exports, and reconstruction
Regulatory & Political Stability (RPS)	Low, Medium, High	Consistency of tariffs, governance, reforms, policy support, and financing access	Tariffs, subsidies, sovereign support, and debt restructuring matter enormously for state-owned enterprises

Source: developed by the authors.

Table 6

Example rules

High-risk scenario	Medium-risk scenario	Low-risk scenario
IF Territorial Stability = Low AND Infrastructure Damage = Severe AND Economic Recovery = Weak AND Political Stability = Low	IF Territorial Stability = Medium AND Infrastructure Damage = Moderate	IF Territorial Stability = High AND Economic Recovery = Strong
THEN Risk Premium = Very High	THEN Risk Premium = Medium	THEN Risk Premium = Low

Source: developed by the authors.

Table 7

Scenario conditions

Scenario	Conditions	Risk Premium Class	Activation	Value
1	Territorial = Low, Damage = Severe, Recovery = Weak, Political = Low	Very High	min (0.8, 0.75, 0.5, 0.4)	0.4
5	Territorial = Low, Damage = Moderate, Recovery = Moderate	High	min (0.8, 0.25, 0.5)	0.25
9	Territorial = High, Damage = Moderate, Recovery = Moderate	Medium	min (0.0, 0.75, 0.5)	0.0

Source: developed by the authors.

Table 8

Output classes

Output Class	Low	Medium	High	Very High
Premium Center	2%	5%	7%	10%

Source: developed by the authors.

ity) method, which is among the most widely applied defuzzification procedures (see Formula 9).

$$RP_{fuzzy} = \frac{\sum(\mu(x) \cdot x)}{\sum \mu(x)}, \quad (9)$$

where: $\mu(x)$ – activated values (see Tbl. 7); x – output class (see Tbl. 8).

Conceptually, this procedure yields a weighted average across the activated risk-premium states.

Defuzzification (Centroid Approximation). The geopolitical risk premium is obtained as the weighted average of the activated output classes (Formula 9):

$$RP_{fuzzy} = (10\% \cdot 0.4 + 7\% \cdot 0.25 + 5\% \cdot 0.0) : (0.4 + 0.25 + 0.0) = 8.84\%.$$

The “Low” output class receives zero activation and is therefore excluded from the defuzzification calculation. Only rules with non-zero activation (Rules 1 and 5) contribute to the defuzzification result.

Then, the adjusted WACC using Formula 3 is:

$$Adjusted\ WACC = 24.68\% + 8.84\% = 33.52\%.$$

The fuzzy-adjusted WACC increases the baseline WACC from 24.68% to 33.52%, reflecting an additional 8.84 percentage points of geopolitical risk premium. This adjustment materially shifts the valuation framework prior to stochastic simulation and constitutes a structural downward correction to enterprise value beyond purely probabilistic variability. The resulting fuzzy-adjusted WACC is used as the central estimate for the stochastic WACC distribution in the Monte Carlo simulation, ensuring that geopolitical risk directly influences all simulated valuation outcomes.

Within the simulation, the weighted average cost of capital (WACC) and the terminal growth rate are treated as stochastic variables, whereas free cash flows are held constant to isolate the effect of capital-market uncertainty and geopolitical risk adjustments on valuation outcomes. Although revenue growth and operating margins were identified as important value drivers, they are held constant in the present implementation to preserve analytical focus on uncertainty in the discount rate and terminal value.

We assume that WACC is normally distributed, centered at the fuzzy-adjusted value of 33.52%, with a standard deviation of 4.5%. The terminal growth rate follows a uniform distribution between 1% and 4%.

Monte Carlo simulation is particularly appropriate for valuation under uncertainty because it replaces fixed parameter assumptions with stochastic inputs that reflect plausible variation in financial conditions. In the present framework, WACC is modeled as a normally distributed variable with a standard deviation of 4.5%, while the terminal growth rate is specified as a uniformly distributed variable on the interval from 1%

to 4%, thereby capturing a broad set of feasible valuation scenarios.

To quantify the effect of parameter uncertainty on enterprise value, a Monte Carlo simulation with 10,000 iterations was performed using stochastic inputs for the discount rate (WACC) and terminal growth rate, while projected Free cash flows were held constant across iterations. This design isolates the valuation impact of uncertainty in capital market conditions and long-run recovery expectations.

The simulated mean WACC of 33.40% closely aligns with the fuzzy-adjusted central estimate of 33.52%, confirming the correct parameterization of the stochastic distribution. The simulated WACC also demonstrates substantial dispersion, reflecting the elevated financing uncertainty associated with a conflict-affected strategic enterprise (see Fig. 1). Across 10,000 iterations, WACC standard deviation is 4.47 percentage points and an observed range from 17.17% to 50.03% (see Appendix 3).

Compared to a Monte Carlo simulation centered on the baseline WACC of 24.68%, the fuzzy-adjusted simulation exhibits a substantial leftward shift in the valuation distribution, indicating that geopolitical risk contributes materially to the observed valuation discount. These results indicate that relatively small changes in perceived risk conditions can translate into large shifts in discount rates and, consequently, enterprise value. Given the long-duration nature of DCF valuation, this sensitivity is economically important: lower-tail WACC realizations generate disproportionate upside in terminal value, whereas higher discount-rate scenarios materially compress valuation outcomes (see Tbl. 9).

Table 9

Probabilities of WACC exceeding selected thresholds (%)

WACC ≥	25%	27%	30%	32%
Confidence level				
Empirical	97%	93%	78%	62%
Theoretical	97%	92%	78%	62%

Source: developed by the authors.

The findings therefore confirm that the cost of capital is a dominant transmission channel through which geopolitical and macro-financial uncertainty affects the valuation of Ukrainian Railways. The simulation produced an estimated mean enterprise value of USD 947 million, with a median of USD 904 million and a standard deviation of USD 267 million. The difference between mean and median indicates a positively skewed valuation distribution, driven by a limited number of high-value outcomes under favorable

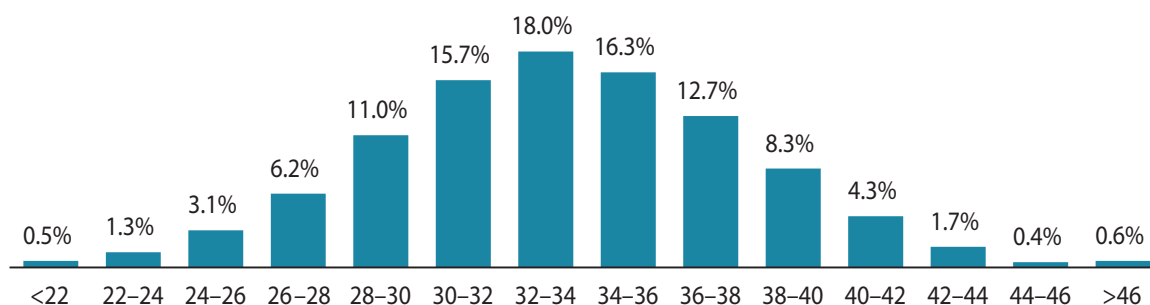


Fig. 1. WACC distribution based on 10.000 simulation iterations

combinations of lower discount rates and stronger terminal growth assumptions.

Compared with the deterministic baseline valuation of USD 1.551 million, the stochastic mean implies a substantial reduction in estimated enterprise value. This corresponds to an approximate 39% stochastic discount, highlighting the sensitivity of conventional DCF outputs to uncertainty in discount rates and long-term growth assumptions. The lower tail of the distribution is particularly informative for decision-making under uncertainty (see *Tbl. 10*). The estimated 95% confidence floor equals USD 601 million, implying that only 5% of simulated outcomes fall below this level. This provides a useful downside reference point for creditors, policymakers, and restructuring stakeholders evaluating stress scenarios for Ukrainian Railways.

Table 10

**Enterprise Value Thresholds by Confidence Level
(USD million)**

Confidence Level	99%	95%	90%	80%
EV ≥	509	601	654	729

Source: developed by the authors.

Tbl. 11 shows that the probability of enterprise value exceeding USD 750 million is 77% under both the empirical and theoretical estimates. At higher thresholds, the likelihood declines sharply: the empirical probabilities of exceeding USD 1.000 million, USD 1.250 million, and USD 1.500 million are 35%, 12%, and 4%, respectively, compared with theoretical estimates

Table 11

**Probabilities of Enterprise Value Exceeding
Selected Thresholds**

EV (USD million) ≥	750	1.000	1.250	1.500
Confidence level				
Empirical	77%	35%	12%	4%
Theoretical	77%	42%	13%	2%

Source: developed by the authors.

of 42%, 13%, and 2%. Thus, the simulated distribution is concentrated mainly below USD 1.0 billion, while valuations approaching the deterministic benchmark remain low-probability outcomes.

The simulated valuation outcomes exhibit clear non-normality. The estimated skewness of 1.21 and kurtosis of 2.84 indicate a right-tailed distribution with occasional high-value realizations (see Appendix 3). In practical terms, while extreme upside scenarios remain possible, the bulk of simulated outcomes are concentrated materially below the deterministic benchmark. At the upper end of the distribution, values above USD 1.5 billion occur relatively infrequently (2–4%), indicating that deterministic valuations near the baseline estimate require a combination of unusually favorable financing conditions and optimistic terminal assumptions.

DISCUSSION

The empirical results demonstrate that incorporating uncertainty fundamentally alters the valuation of Ukrainian Railways. The deterministic DCF estimate of USD 1.551 million contrasts sharply with the stochastic mean valuation of USD 947 million, implying an approximate 39% reduction once uncertainty in discount rates and long-term growth is considered. This finding confirms that traditional single-point valuation frameworks substantially overstate enterprise value in environments characterized by elevated volatility.

More importantly, the integration of fuzzy logic introduces an additional structural adjustment to valuation by incorporating geopolitical risk. The fuzzy inference system produces a risk premium of 8.8%, increasing the discount rate from 24.68% to 33.52%. This adjustment represents a systematic shift in valuation conditions, rather than a purely probabilistic fluctuation. As a result, the valuation framework reflects not only variability in financial inputs but also the broader uncertainty associated with conflict dynamics, institutional stability, and infrastructure integrity.

Taken together, the findings indicate that uncertainty affects valuation through two distinct yet complementary channels. Stochastic uncertainty, op-

erationalized through Monte Carlo simulation, captures variability in key financial parameters, whereas structural uncertainty, represented through fuzzy logic, captures ambiguity in geopolitical conditions. The interaction of these channels yields a more comprehensive and realistic representation of enterprise value under conditions of extreme uncertainty.

The study makes several *contributions* to the literature on corporate valuation under uncertainty.

First, it extends the traditional DCF framework by integrating probabilistic and possibilistic approaches within a single coherent model. While prior research has applied Monte Carlo simulation to valuation problems and, separately, fuzzy logic to decision-making under uncertainty, these methods are typically used in isolation. This study demonstrates how they can be combined in a structured manner, with fuzzy logic defining the risk environment and Monte Carlo simulation exploring the distribution of outcomes within it.

Second, the paper introduces a formal mechanism for incorporating qualitative geopolitical risk into valuation models. Existing valuation frameworks typically rely on ad hoc adjustments to discount rates or scenario-based narratives. In contrast, the proposed approach uses a rule-based fuzzy inference system to translate qualitative assessments into a quantitative risk premium. This improves transparency, consistency, and replicability.

Third, the study contributes to the emerging literature on valuation under extreme conditions, particularly in conflict-affected economies. By applying the model to Ukrainian Railways, the paper provides empirical evidence that geopolitical risk can materially alter valuation outcomes beyond what is captured by conventional financial risk factors. This supports the view that valuation models must be adapted when applied to environments characterized by structural instability.

The findings also have several *implications* for managerial practice and public policy.

For *investors and financial analysts*, the results indicate that reliance on deterministic DCF models may produce systematically overstated valuations in high-risk settings. By explicitly incorporating both stochastic volatility and structural geopolitical risk, the proposed framework offers a more analytically robust basis for investment assessment and valuation judgment.

For *corporate management*, particularly in state-owned enterprises, the model highlights the importance of reducing perceived geopolitical risk. Improvements in regulatory transparency, infrastructure resilience, and operational stability can materially lower the risk premium and enhance enterprise value.

For *policymakers*, the results underscore the economic cost of geopolitical instability. The concept

of a “geopolitical risk discount” quantifies the value erosion associated with conflict conditions. Policies aimed at institutional stabilization, infrastructure protection, and integration with international markets can therefore have a direct and measurable impact on enterprise valuation.

Despite these contributions, the study remains subject to several limitations that should be considered when interpreting the results.

First, the analysis isolates uncertainty in discount rates and terminal growth while holding operating cash flows constant. This approach allows for a clear identification of the transmission mechanism through the cost of capital but may understate the full impact of geopolitical shocks on enterprise performance.

Second, the fuzzy inference system relies on expert judgment to assign scores and define rule structures. While this enhances flexibility, it introduces a degree of subjectivity. Future research could refine this approach by incorporating data-driven calibration methods.

Third, the empirical analysis is based on a single case study. Although Ukrainian Railways provides a highly relevant and extreme example, broader validation across industries and geographic contexts would strengthen generalizability.

The present analysis also points to several promising *directions for further research*.

One important extension would be to incorporate fuzzy logic not only into the discount rate but also into projected cash flows, thereby allowing operational risk to be modeled more explicitly within the valuation framework. A further avenue would involve developing dynamic specifications in which geopolitical conditions evolve and interact endogenously with financial variables throughout the simulation. The framework could also be applied to other sectors structurally exposed to geopolitical risk, such as energy, logistics, and telecommunications, to assess its broader external validity. In addition, future studies may examine the potential of machine-learning techniques to calibrate membership functions and rule bases more systematically, thereby reducing reliance on purely judgment-based specification.

CONCLUSIONS

This study proposes and empirically validates an integrated valuation framework that combines Discounted Cash Flow analysis, Monte Carlo simulation, and fuzzy logic to address the limitations of traditional valuation models under uncertainty. The results demonstrate that deterministic DCF models fail to capture both the variability and structural uncertainty inherent in conflict-affected environments. Monte

Carlo simulation improves valuation by introducing probabilistic variability, while fuzzy logic further enhances the model by incorporating qualitative geopolitical risk into the discount rate.

Applied to Ukrainian Railways, the framework reveals a substantial divergence between deterministic and uncertainty-adjusted valuations. The observed valuation discount reflects not only financial volatility but also the deeper structural risks associated with geopolitical instability.

The proposed methodology contributes to both theory and practice by offering a transparent, flexible, and integrative valuation approach. It demonstrates that combining probabilistic and possibilistic methods can provide a more comprehensive understanding of enterprise value in complex environments.

In an increasingly uncertain global environment, valuation models must move beyond static assumptions and incorporate multidimensional sources of risk. The present study offers one step in that direction by proposing a framework that is both analytically rigorous and practically applicable.

APPENDICES

Appendix 1. Actual Rule Base

Rule	TCS	IDR	ERO	RPS	RP
Extreme War Stress					
1	Low	Severe	Weak	Low	Very High
2	Low	Severe	–	Medium	Very High
3	Low	–	Weak	Low	High
High Risk					
4	Medium	Severe	Weak	–	High
5	Low	Moderate	Moderate	–	High
6	–	Severe	–	Low	High
7	Medium	–	Weak	Medium	High
Transitional / Recovery					
8	Medium	Moderate	Moderate	Medium	Medium
9	High	Moderate	Moderate	–	Medium
10	–	–	Strong	Medium	Medium
Stabilization					
11	High	Low	Strong	High	Low
12	High	–	Strong	High	Low

Appendix 2. Membership Functions

Territorial Control Stability = 35

Fuzzy Set	Low	Medium	High
Range	0–50	30–70	60–100
Memberships	0.8	0.2	0.0

Infrastructure Damage Risk = 80

Fuzzy Set	Low	Moderate	Severe
Range	0–30	20–70	60–100
Memberships	0.0	0.25	0.75

Economy Recovery Prospects = 45

Fuzzy Set	Weak	Moderate	Strong
Range	0–50	30–70	60–100
Memberships	0.5	0.5	0.0

Regulatory & Political Stability = 50

Fuzzy Set	Low	Medium	High
Range	0–50	30–70	60–100
Memberships	0.4	0.6	0.0

Territorial Control Stability Membership Functions:

$\mu_{\text{Low}}(x) =$	$\mu_{\text{Medium}}(x) =$
1.0 if $x \leq 30$	0.0 if $x \leq 30$
$(50 - x) / 20$ if $30 < x < 50$	$(x - 30) / 20$ if $30 < x < 50$
0.0 if $x \geq 50$	1.0 if $50 \leq x \leq 50$
	$(70 - x) / 20$ if $50 < x < 70$
	0.0 if $x \geq 70$

$\mu_{\text{High}}(x) =$
0.0 if $x \leq 60$
$(x - 60) / 20$ if $60 < x < 80$
1.0 if $x \geq 80$

Appendix 3. Descriptive Statistics

Metric	WACC	PV of Free Cash Flows	PV of Terminal Value	Enterprise Value
Mean	33.40%	358	589	947
Median	33.41%	352	552	904
Standard Deviation	4.47%	66	202	267
Kurtosis	0.02	0.54	4.01	2.84
Skewness	0.02	0.54	1.45	1.21
Range	32.86 p.p.	511	2,079	2,580
Minimum	17.17%	176	200	383
Maximum	50.03%	687	2,279	2,963

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[https://doi.org/10.1016/S0019-9958\(65\)90241-X](https://doi.org/10.1016/S0019-9958(65)90241-X)
- This research received no external funding.
The authors declare no conflict of interest.
The generative tool Grammarly was used to improve the language clarity and editorial quality of the manuscript. All conceptual development, methodology, analysis, interpretation of results, and final content were created and verified by the authors.
- Стаття надійшла до редакції / Received: 02.07.2026
Статтю прийнято до публікації / Accepted: 15.07.2026
Оприлюднено / Published: 20.08.2026