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THE IMPACT OF MACROECONOMIC AND POLITICAL STABILITY ON NUCLEAR POWER PLANT CONSTRUCTION DURATION: DEVELOPMENT AND APPLICATION OF THE MAPSS INDEX

Petr Talášek

Czech Technical University in Prague, Faculty of Civil Engineering, Thákurova 7, 166 29 Prague, Czech Republic; p.talasek@gmail.com

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ABSTRACT

This study examines the impact of a country's macroeconomic and political stability on the construction duration of nuclear power plant (NPP) projects. Despite extensive research into technical and managerial causes of delays, the role of national stability remains underexplored. This research develops the Macroeconomic and Political Stability Score (MAPSS), a composite risk assessment index designed to quantify national-level risks affecting project delivery. A stratified sample of 96 NPP projects was analysed using Pearson correlation, Welch's t-tests, and multiple linear regression to evaluate the relationship between key economic indicators, political events, and construction timelines. The results show that national economic crises, international crises, government collapses, and armed conflicts are significantly associated with extended construction durations, whereas factors such as inflation and international sanctions showed no meaningful effect. The MAPSS index demonstrated a statistically significant correlation with project duration ($r = -0.390$, $p < 0.001$), confirming its practical value for early-stage risk assessment. The findings underscore that external macroeconomic and political factors are critical determinants of nuclear project delivery. This research offers a novel framework to support policymakers, investors, and planners in evaluating stability-related risks prior to committing to nuclear infrastructure investments.

KEYWORDS

Nuclear Power Plant, Construction Duration, Macroeconomic Stability, Political Stability, Risk, MAPSS, Project Delay

INTRODUCTION

The global transition towards low-carbon energy sources positions nuclear power at the centre of many national energy strategies due to its capacity to deliver reliable baseload electricity with minimal CO_2 emissions [1]. Nuclear energy is increasingly recognized as a key component of energy security and long-term climate objectives [2]. The successful deployment and continuous innovation of such sustainable energy technologies rely heavily on consistent public funding and aligned strategic policies at both national and supranational levels [3]. Despite this strategic importance, the delivery of new nuclear power plants (NPPs) continues to face persistent challenges

- most notably high capital costs and extended construction durations [4] - which frequently undermine project viability and investor confidence [5]. Given their scale, duration, and stringent safety and quality requirements, contemporary nuclear new-builds occupy the broader class of long-duration infrastructure megaprojects, where schedule performance is pivotal to overall viability. These challenges are compounded by the inherent complexity of nuclear projects.

Prior research on schedule performance in nuclear new builds has predominantly focused on internal project factors and regulatory drivers. Empirical studies link overruns and delays to design quality/changes, documentation and interface management, contractor capability, supply-chain bottlenecks, and project-management discipline, alongside licensing scrutiny and regulatory review cycles [6]. Evidence from the literature consistently highlights organizational and managerial determinants as central drivers of nuclear power plant project performance. Factor-analytic studies identify construction management practices, coordination mechanisms, and the prior experience of contractors and integrated project teams as critical success factors influencing schedule adherence and cost control [7]. Complementary evidence from structured risk-register analyses of U.S. nuclear power plant projects indicates that design-related risks constitute the most frequently occurring and systematically significant risk category, often cascading into additional procurement, rework, and interface management complications during execution [8]. Furthermore, longitudinal analyses of historical cost escalation demonstrate that more than half of observed cost increases can be attributed to management deficiencies, regulatory adaptation challenges, labour productivity shortfalls, and coordination inefficiencies, rather than to the intrinsic cost of reactor technology or major hardware components [9]. Post-accident assessments further anticipate stricter safety requirements and regulatory delays that amplify costs and timelines [10].

In contrast, a smaller but expanding body of work indicates that country-level conditions materially shape delivery risk. Multicriteria assessments for international NPPs rank policy change, political instability, and public intervention among the highest schedule-risk contributors, alongside regulatory approval and incomplete designs [11]. Cross-region analysis of 1955–2016 reactor builds shows discontinuities in both lead time and cost that are country-specific and "induced by national policies and regulatory frameworks," underscoring macro-institutional influences on delivery performance [12]. Broader megaproject evidence also links outcomes to governance quality and external stakeholder dynamics [13], while comparative risk-management frameworks formalize national-environment risk classes (political/policy, economy/finance, legal, social) and find NPPs exhibit higher risk profiles than fossil/gas projects across the life cycle [14,15]. Program-level SWOT analyses of newcomer nuclear states, such as Ghana's proposed nuclear energy programme, identify policy discontinuity, governance fragility, institutional capacity gaps, and security vulnerabilities as structural risks that may constrain timely and stable nuclear deployment [16].

Taken together, the literature supports the primacy of internal and regulatory explanations, but it also points to a consequential and uneven macro-political layer that remains underexplored. To address this gap, we propose the Macroeconomic and Political Stability Score (MAPSS), a composite index that integrates continuous macroeconomic indicators with discrete political-event markers to quantify country-level delivery risk. MAPSS provides a systematic way to capture national stability conditions and to test their association with construction duration in nuclear new builds.

The research is guided by the following research questions:

RQ1: To what extent are national macroeconomic and political stability conditions associated with NPP construction duration?
RQ2: Can these conditions be summarised in a composite index (MAPSS) that explains variation in construction duration more effectively than single indicators?
RQ3: Can MAPSS serve as a composite index suitable for early-stage risk screening of NPP projects?

Accordingly, we test the following hypotheses:

H1: Lower national macroeconomic and political stability (lower MAPSS) is associated with longer NPP construction durations.
H2: MAPSS explains significantly more variance in construction duration than any single constituent indicator.
H3: MAPSS demonstrates predictive accuracy consistent with early-stage risk screening.

This study addresses a critical gap in the nuclear project management literature by operationalizing macroeconomic and political stability into a composite, reactor-linked index (MAPSS) and empirically testing its association with construction duration. While prior research has emphasized project-internal and regulatory drivers of delay, systematic quantification of macro-institutional influences remains limited. By introducing and validating MAPSS, the study expands the explanatory framework for nuclear megaproject performance beyond the project boundary.

MATERIALS AND METHODS

Study design

This study employed a quantitative research design to examine whether macroeconomic and political stability during the construction phase is statistically associated with the construction duration of nuclear power plants (NPPs). The objective was to evaluate whether key indicators of national macroeconomic and political stability influence construction duration. The analytical framework was directly aligned with the three research questions outlined in the Introduction.

Data sources

The initial dataset comprised 412 nuclear reactors constructed worldwide between 1968 and 2024, all of which achieved operational status. The dataset was obtained from the Nuclear Planet database [17], an open-access and continuously updated resource that documents the development and operational history of nuclear energy infrastructure worldwide.

The Data Collection Procedure

Data required for the statistical analysis was manually collected through a structured search of official and publicly accessible databases and archives. Economic data was sourced from the World Bank Databank [18], specifically the GDP % annual growth indicator, unemployment and inflation. Political and crisis-related data was obtained from the U.S. Department of State Office of the Historian [19], which documents international crises and geopolitical events, and the U.S. Department of the Treasury's Office of Foreign Assets Control (OFAC) Sanctions List [20], which records international sanctions. Additionally, major economic crises, including the Great Recession, were verified through the Federal Reserve History archives [21]. All collected data was compiled into a structured spreadsheet and rigorously cross-checked to ensure consistency prior to statistical analysis.

Selection criteria

Prior to sample selection, projects lacking essential project-level data were excluded to ensure data completeness and consistency. The inclusion criteria required the availability of the following core project attributes: reactor name, operating country, construction start year, and commercial operation date. The dependent variable—construction duration—was measured in months, calculated from the date of physical construction commencement to the date of first grid connection.

To enable robust statistical analysis, projects were further required to have complete data for the following independent variables covering the entire construction period:

Gross Domestic Product (GDP);
Inflation Rate;
Unemployment Rate;
Economic crisis – International;
Economic crisis – National;
Government Collapse;
International Sanctions;
Armed Conflicts.

As a result of these criteria, 92 projects were excluded for lacking key economic or political data relevant to the construction period. Common reasons included prolonged geopolitical isolation, lack of independent national data during periods of political transition, or unavailability of disaggregated statistics during the Soviet era. After applying all exclusion criteria, the final dataset comprised 320 nuclear reactor projects with complete and analysable data.

From this dataset, a stratified random sample of 30% (n = 96) was selected to ensure proportional representation of projects with short, average, and extended construction durations. Stratification was based on total construction duration (in months), which served as the key variable for defining the strata. This approach balanced representativeness with analytical tractability: while the full dataset of 320 projects was theoretically available, focusing on a 30% stratified subsample preserved proportional representation across short, medium, and long-duration projects while keeping the dataset manageable for detailed manual verification, consistency checks, and cross-referencing of economic and political indicators.

First, the 33rd and 66th percentiles of construction duration were calculated using Microsoft Excel. These thresholds divided the projects into three groups: short, average, and long-duration projects. Each project was then assigned to its respective group. A random number was generated for each project. Within each group, projects were sorted in ascending order based on the generated random numbers, and the top entries corresponding to 30% of each group were selected.

This method ensured a proportionally random selection across the defined strata, preserving the original distribution of construction durations within the sample. All sampling procedures were performed in Microsoft Excel. This transparent, spreadsheet-based approach ensures that the procedure can be directly replicated by other researchers without specialist software.

DEVELOPMENT OF THE MACROECONOMIC AND POLITICAL STABILTY SCORE (MAPSS)

To enable composite analysis and reduce dimensionality among the independent variables, a unified metric—the Macroeconomic and Political Stability Score (MAPSS)—was developed. The MAPSS is an original composite index designed to quantify the level of national macroeconomic and political stability during a nuclear power plant's construction period.

Weighting Scheme

The weighting structure, which assigns the relative impact of individual events on national stability, reflects the theoretical assumption that macroeconomic conditions exert a marginally greater influence on construction timelines than political factors, primarily through effects on financing conditions, labor markets, and supply chain stability [22]. Nevertheless, political events—such as regime changes, sanctions, or armed conflicts—can trigger immediate, acute disruptions that are not necessarily preceded by economic signals [5,23].

Accordingly, the MAPSS framework distinguishes between two categories of indicators:

Continuous macroeconomic indicators—GDP growth, inflation, and unemployment—which tend to fluctuate together and collectively represent the underlying economic resilience or vulnerability of a nation; and

Discrete crisis events—government changes, international sanctions, armed conflicts, and national or international financial crises—which represent sudden, severe shocks that can disrupt goods, services, financing, and ultimately hinder national industrial capacity.

This distinction reflects well-documented patterns in economic history. For example, the 1973 oil crisis, 1979 energy crisis, 2008 global financial crisis, and the 2020 COVID-19 pandemic each produced abrupt economic contractions that led to severe supply chain disruptions, labor shortages, and capital constraints affecting infrastructure and energy projects globally [24]. These crises are explicitly included in the dataset used for this study and serve as examples of the kind of acute destabilizing events captured in the MAPSS index.

The selection of weights follows a hybrid approach combining empirical evidence from the dataset with established practices in composite index construction. The weighting is aligned with methodologies employed by international institutions such as the OECD, World Bank, and IAEA [25], where high-impact, low-frequency events—such as armed conflict or government collapse—are retained with substantial weight despite their relatively infrequent occurrence in historical data.

This reflects a widely accepted principle in risk-based composite modelling: low-frequency, high-impact events must be accounted for to preserve the predictive and practical utility of the index. For example, while inflation may exhibit a muted effect on project durations due to mitigation strategies embedded in contractual structures, the occurrence of a national economic crisis or armed conflict has the potential to disrupt construction entirely. Therefore, such discrete but critical variables are weighted comparably to continuous macroeconomic indicators.

The MAPSS is structured as a weighted aggregate of two sub-indices:
Economic Stability Sub-index - total weight 0.55 (55%);
Political Stability Sub-index - total weight = 0.45 (45%).

These two domains are further divided into eight indicators:

Economic Stability Sub-index:
GDP: Growth Rate (average % for duration) - 0.15 (15%) weight;
Inflation Rate (average % for duration) - 0.10 (10%) weight;
Unemployment Rate (average % for duration) - 0.10 (10%) weight;
Economic crisis – International (binary) – 0.10 (10%) weight;
Economic crisis – National (binary) – 0.10 (10%) weight.

Political Stability Sub-index:
Government Changes (binary) - 0.15 (15%) weight;
International Sanctions (binary) - 0.15 (15%) weight;
Armed Conflicts (binary) - 0.15 (15%) weight.

Data Transformation Process

All independent indicators identified in Section 2.4. were normalized or coded onto a standardized scale ranging from 0 (lowest stability) to 1 (highest stability).

Economic Continuous Variables - GDP, Inflation, Unemployment - was transformed using min–max normalization on scale ranging from 0 (lowest stability) to 1 (highest stability) to calculate X_norm:

$$X\_norm = \frac{X - X\_min}{X\_max - X\_min}$$

Where:
X = observed raw value;
X_min and X_max = minimum and maximum values within the dataset.

Economic and Political Binary variables — International Crisis, National Crisis, Government collapse, International sanctions, armed conflicts, and economic crises — were coded as:
1 = Event occurred (instability);
0 = event did not occur (stability).

Directionality was adjusted where necessary, so that lower values for negative factors (e.g., inflation, unemployment) corresponded to higher stability scores:
X_inv = 1 - X_norm.

Formula for MAPSS

The following outlines the computational hierarchy:
MAPSS = Economic Sub-Index + Political Sub-Index.

Where:
Economic Sub-Index = (0.15 x GDP_norm) + (0.10 x Inflation_norm) + (0.10 x Unemployment_norm) + (0.10 x Economic Crisis - International_norm) + (0.10 x Economic Crisis - National_norm);
Political Sub-Index = [0.15 x (1 – GovCollaps_norm)] + [0.15 x (1 – Sanctions_norm)] + [0.15 x (1 – Conflict_norm)].

Tools and Data Availability

All calculations were performed using Microsoft Excel 365. The Excel workbook used for MAPSS calculation, including all normalization formulas and weighting logic, is uploaded and available at: https://doi.org/10.5281/zenodo.19469868. This choice of platform was made to ensure maximum accessibility and reproducibility, so results can be verified without specialized statistical software.

Reproducibility Statement

All data sources used are publicly accessible. Data availability is unrestricted, and all computation procedures are transparent within the provided supplementary materials. No proprietary or restricted data were used.

ANALYTICAL METHODS

Statistical analysis was performed using Microsoft Excel on the dataset of 96 nuclear power plant (NPP) projects using a combination of Pearson’s correlation coefficient, Welch’s t-test, and multiple linear regression analysis. These methods were employed to investigate the existence and strength of statistically significant relationships between macroeconomic and political stability indicators and the construction duration of NPPs.

Correlation and Group Difference Analysis

Pearson’s correlation analysis was used to assess the direction and magnitude of linear associations between continuous economic indicators—such as GDP growth, inflation, and unemployment—and the construction duration.

Welch's t-test, complemented by Levene's test for homogeneity of variances, was applied to compare mean construction durations across binary categorical variables, including the occurrence of international economic crises, national economic crises, government collapse, international sanctions, and armed conflicts. Cohen's d was calculated to quantify effect sizes for all group comparisons.

Multiple Linear Regression Analysis

A multiple linear regression analysis was conducted to evaluate the combined influence of all independent variables—both continuous and binary—on construction duration. This approach enabled the identification of the most influential predictors while controlling for the effects of other variables. The regression model included GDP growth, inflation, unemployment, international and national economic crises, government collapse, international sanctions, and armed conflicts as predictors.

The statistical significance, direction, and magnitude of each predictor's coefficient were evaluated, along with overall model fit statistics, including R^2 and adjusted R^2. This analysis provided a holistic understanding of how macroeconomic and political stability factors jointly affect project timelines.

Regression Diagnostics

Prior to interpreting the regression results, key assumptions of multiple linear regression were evaluated to ensure the robustness of the analysis:

Multicollinearity: Assessed using Variance Inflation Factors (VIF), with all predictors recording VIF values below 2, indicating no multicollinearity concerns.

Homoscedasticity: Evaluated via residuals vs. fitted values plots, which showed randomly distributed residuals, indicating homoscedasticity was met.

Normality of Residuals: Assessed using histograms and Q–Q plots. Residuals were approximately normally distributed, with minor tail deviations common in applied datasets but not severe enough to undermine model validity.

Independence of Errors: Not deemed critical as the data are cross-sectional, not time-series.

Linearity: Confirmed through preliminary correlation analysis and inspection of residuals, supporting the appropriateness of the linear model form.

MAPSS Validation Analysis

Additionally, the validity of the composite MAPSS score as a predictive metric was assessed using Pearson's correlation analysis and simple linear regression against construction duration. This analysis evaluated the extent to which MAPSS functions as a reliable single-variable predictor of construction delays in NPP projects.

RESULTS

Correlation Between Economic Indicators and Construction Duration

Pearson correlation analysis revealed a moderate but statistically significant negative correlation between gross domestic product (GDP) growth and NPP construction duration ($r = -0.215$, $p = 0.036$), suggesting that higher GDP growth during the construction period was associated with shorter project durations. A simple linear regression yielded a slope of −4.82, an intercept of 115.46, and a coefficient of determination (R^2) of 0.046, indicating only modest explanatory power of GDP alone.

By contrast, Pearson correlation analysis revealed no statistically significant relationship between average inflation during the construction period and NPP construction duration ($r = 0.006$, $p = 0.954$). A simple linear regression confirmed this result, yielding a slope of 0.052, an intercept of

95.36, and an R^2 of 0.000, indicating that inflation exerted no meaningful influence on project duration within the sample.

Similarly, Pearson correlation analysis identified a moderate and statistically significant positive correlation between average unemployment during the construction period and NPP construction duration (r = 0.226, p = 0.027), indicating that higher unemployment was associated with longer project durations. A simple linear regression yielded a slope of 5.03, an intercept of 67.26, and an R^2 of 0.051, suggesting that unemployment alone accounts for a modest portion of the variability in construction timelines.

Welch's t-test indicated a statistically significant difference in construction durations between projects executed during periods of international economic crisis and those constructed in more stable economic conditions (mean = 102.07 months vs. 71.75 months; t = 3.20, p = 0.002). Levene's test confirmed that the assumption of equal variances was not violated (W = 1.88, p = 0.173). The corresponding Cohen's d of 0.622 suggests a moderate effect size, indicating that international economic crises had a meaningful adverse impact on project timelines.

A similar pattern was observed for national economic crises. Welch's t-test revealed a statistically significant difference in construction durations between projects affected by national economic crises and those that were not (mean = 121.3 months vs. 77.5 months; t = 3.35, p = 0.0016). Levene's test indicated a violation of the assumption of equal variances (W = 6.03, p = 0.016), justifying the use of Welch's correction. The computed Cohen's d of 0.739 indicates a moderate to large effect size, demonstrating that national economic crises substantially increased project durations.

Impact of Political Disruptions, and Conflict on Construction Duration

In the case of government collapse, Welch's t-test revealed a difference in construction durations that did not reach statistical significance (mean = 122.88 months vs. 86.20 months; t = 1.81, p = 0.082). Levene's test indicated a significant violation of the equal variance assumption (W = 8.29, p = 0.0049), warranting the use of Welch's correction. Despite the lack of statistical significance, the computed Cohen's d of 0.497 suggests a moderate effect size, indicating that projects undertaken during periods of government collapse tended to experience longer durations, though this trend was not conclusive within the sample.

In contrast, the analysis revealed no statistically significant relationship between the presence of international sanctions during the construction period and NPP construction duration (mean = 99.65 months vs. 94.30 months; t = 0.484, p = 0.630). Levene's test indicated that the assumption of equal variances was satisfied (W = 0.026, p = 0.873). The computed Cohen's d of 0.099 reflects a negligible effect size, suggesting that international sanctions had no observable influence on project timelines within this dataset.

Finally, Welch's t-test demonstrated a statistically significant difference in construction durations between projects affected by armed conflicts and those not affected (mean = 108.00 months vs. 74.40 months; t = 3.31, p = 0.0013). Levene's test indicated that the assumption of equal variances was not violated (W = 2.27, p = 0.135). The computed Cohen's d of 0.639 represents a moderate effect size, highlighting that armed conflicts were associated with substantially longer project durations.

Multiple Linear Regression Analysis

To assess the combined influence of all macroeconomic and political stability indicators on NPP construction duration, a multiple linear regression analysis was conducted. The overall model was statistically significant ($F(8, 87) = 3.94$, p = 0.0005), explaining 26.6% of the variance in construction duration ($R^2 = 0.266$; adjusted $R^2 = 0.198$).

The results indicated that national economic crises ($\beta = 44.24$, p = 0.001) and government (regime) collapse ($\beta = 29.24$, p = 0.040) were significant predictors of longer construction durations. A near-significant effect was also observed for international economic crises ($\beta = 29.11$, p = 0.079).

Other variables, including GDP growth, inflation, unemployment, international sanctions, and armed conflicts, did not achieve statistical significance in the multivariate model, despite some showing significance in bivariate analyses. This suggests that certain contextual factors—particularly major national-level economic and political disruptions—exert a disproportionately stronger influence on project timelines when considered jointly with other factors.

Composite Stability Index (MAPSS) and Project Duration

Finally, the MAPSS composite index was tested as a single aggregated predictor of construction duration. Pearson correlation analysis revealed a moderate but statistically significant negative correlation between MAPSS and NPP construction duration ($r = -0.390$, $p = 0.000087$), indicating that higher macroeconomic and political stability was associated with shorter project durations. A simple linear regression yielded a slope of −114.46, an intercept of 159.91, and an R^2 of 0.152. This suggests that MAPSS alone explains over 15% of variance in construction duration, outperforming any individual variable. These findings provide initial evidence that MAPSS captures stability-related risks more effectively than single measures and offers preliminary predictive value for early-stage risk screening.

DISCUSSION

The results of this study provide robust empirical evidence within the analysed dataset that macroeconomic and political stability can significantly influence the construction duration of nuclear power plant (NPP) projects. This finding aligns with and extends the existing body of literature, which increasingly acknowledges that the performance of large-scale infrastructure projects depends not only on internal technical and managerial factors but also on broader national and geopolitical conditions [26]. It reinforces the perspective that external contextual factors, often overlooked in traditional project management models, play a critical role in shaping project delivery outcomes [27]. In particular, the results confirm that external crises and instability operate as significant schedule risks, thereby supporting the hypothesis set out in this study.

GDP Growth and Project Duration

A modest but statistically significant negative correlation between GDP growth and construction duration supports the hypothesis that stronger economic performance facilitates more efficient project execution. Economies experiencing continuous growth are typically characterized by higher industrial output, more resilient supply chains, robust labour markets, and reliable access to financing—all of which are critical enablers for delivering capital-intensive, technologically complex projects such as NPP construction. This outcome is consistent with broader infrastructure literature, which links favorable macroeconomic conditions to improved project performance [11]. For instance, the competitiveness and resilience of foundational sectors, such as the steel industry, are closely tied to macroeconomic stability and decarbonization policies, acting as essential prerequisites for the secure material supply chains required in large-scale energy infrastructure [28].

Within the MAPSS index, GDP growth is retained as a continuous stabilizing indicator, reflecting the long-term economic resilience that underpins project delivery.

Unemployment and Project duration

The observed positive correlation between unemployment and construction duration further reinforces this relationship from the inverse perspective. Higher unemployment typically signals broader economic weakness, translating into market uncertainty, reduced investment, labour productivity challenges, and disruptions within critical supply chains.

Within MAPSS, unemployment is retained as a negatively weighted indicator, capturing the vulnerability of projects situated in fragile labour market contexts and constrained industrial environments.

Inflation and Project Duration

By contrast, the analysis revealed no statistically significant relationship between inflation and construction duration. This null result is best explained by the contractual and financial structures characteristic of nuclear megaprojects. Inflationary pressures typically influence financing costs rather than schedules. Risk is mitigated at the contract stage through mechanisms such as forward pricing, escalation clauses, currency hedging, and indexation. These provisions anticipate cost growth over long lifecycles and reduce the likelihood of direct schedule disruption. Thus, while inflation remains a standard macroeconomic indicator, its impact on construction duration appears limited in practice.

Despite the absence of a significant effect, inflation is retained within the MAPSS index to maintain consistency with broader macroeconomic theory, where it remains a standard indicator of economic stability and recessionary risk [29]. Its inclusion ensures that MAPSS remains generalizable beyond the nuclear domain, thereby reinforcing its value as a composite tool for early-stage risk screening.

International Economic Crisis and Project Duration

Projects executed during periods of international economic crisis experienced substantially longer construction durations compared to those constructed under stable economic conditions. The corresponding effect size is consistent with established evidence that systemic downturns constrain liquidity, destabilize supply chains, and heighten uncertainty in capital-intensive megaprojects [30]. Similar findings were observed following the COVID-19 pandemic, where global supply chain disruptions and inflationary pressures caused severe project delays across major infrastructure sectors [31].

Within MAPSS, international crises are retained as discrete, high-impact indicators, complementing the continuous measures of GDP, unemployment, and inflation.

National Economic Crisis and Project Duration

A similar but even more pronounced effect was observed for national economic crises. Projects affected by national-level crises exhibited a mean construction duration of 121.3 months compared to 77.5 months for unaffected projects. These results are consistent with existing literature on megaproject vulnerability under financial distress and highlight how crises at both global and national scales can disrupt supply chains, strain labour markets, and create financing constraints [32].

The comparable magnitude of impact across international and national crises supports their equal weighting in the MAPSS framework. Their inclusion ensures that MAPSS captures both gradual macroeconomic conditions and severe financial shocks, providing a balanced and practical tool for risk assessment in nuclear construction projects.

Government Collapse as Delay Drivers

While government collapse was associated with considerable delays, the finding did not reach conventional statistical significance. This may be attributable to the limited sample size or to the heterogeneity of what constitutes a “collapse,” ranging from transitional governments to full regime breakdowns. Nonetheless, qualitative evidence suggests that such political disruptions can have substantial and long-lasting effects on nuclear project delivery.

A well-documented example of a project affected by full regime collapse is Iran’s Bushehr Nuclear Power Plant, which was originally initiated in the 1970s with German assistance but experienced severe delays following the 1979 Islamic Revolution and the subsequent imposition of international sanctions. The regime change led to the withdrawal of Western contractors and a prolonged construction halt; the project only resumed years later under Russian cooperation and was ultimately completed in 2011—more than three decades after its initial start [3,33]. This case illustrates how profound political transitions can destabilize project governance, financing, and international cooperation, causing multidecade schedule overruns.

Beyond full regime collapse, a broader spectrum of political instability may also contribute to delivery risks. Administrative failures, legislative deadlocks, and frequent leadership turnovers—though less visible than regime change—can similarly delay project approvals and implementation. For instance, the inability of authorities to operationalize newly adopted permitting laws has been shown to prolong construction approvals at the national level [34]. Such forms of governance dysfunction, while short of formal collapse, still represent systemic political instability with tangible effects on project delivery.

Despite the lack of statistical significance within this dataset, the substantial effect size and multiple documented historical examples support the decision to retain government collapse within the MAPSS framework. This aligns with established practices in risk-based modelling, where high-impact but lower-frequency events are incorporated due to their disproportionate potential to disrupt project delivery.

International Sanctions as Delay Drivers

The presence of international sanctions did not exhibit a statistically significant effect on project timelines within this dataset. This finding warrants closer examination, as the consequences of sanctions may operate through mechanisms not fully captured by construction-duration metrics alone. Sanctions can exert delayed or lagged effects, particularly when imposed prior to project initiation, by constraining access to financing, technology transfer, or international partnerships. In such cases, sanctions may inhibit project approval, financial close, or commencement rather than extend duration once physical construction has begun.

Moreover, sanctions vary considerably in severity, scope, and sectoral targeting. Some states may partially offset their effects through alternative suppliers, domestic industrial substitution, or geopolitical realignment, thereby attenuating direct impacts on ongoing construction activities.

Historical evidence nevertheless demonstrates that sanctions can exert profound and prolonged effects under specific conditions. India, for example, faced comprehensive international sanctions following its 1974 nuclear test, resulting in the withdrawal of foreign suppliers and the termination of fuel and technology agreements with Canada and the United States. These measures constrained elements of India’s civilian nuclear programme, including operations at Tarapur, and necessitated the development of indigenous technological capabilities. A subsequent wave of sanctions in 1998 further restricted international cooperation until the early 2000s [35]. This case illustrates that when sanctions directly target nuclear policy and supply chains, they can materially disrupt civilian nuclear infrastructure development.

Therefore, while sanctions did not emerge as a statistically significant determinant of construction duration across the broader sample, their effects may be conditional, temporally lagged, or manifested through project non-initiation or cancellation rather than extended build times. For this reason, international sanctions are retained within the MAPSS framework as a low-frequency but potentially high-impact indicator, consistent with the index’s objective to capture both structural macroeconomic conditions and episodic geopolitical disruptions.

Armed Conflicts as Delay Drivers

Armed conflict emerges as a substantial external determinant of nuclear construction performance. Projects undertaken in conflict-affected environments required, on average, approximately 34 additional months to complete compared with those in stable conditions. This magnitude of delay underscores that geopolitical instability constitutes a material and operationally significant risk factor for nuclear megaproject delivery.

This finding aligns with theoretical expectations and historical evidence. Armed conflicts can disrupt construction directly through physical damage to infrastructure, restrictions on labour mobility, and supply chain interruptions, while also indirectly affecting financing and logistics as national resources are diverted toward defence activities [36]. Even conflicts that occur outside the immediate project area can generate ripple effects through regional instability, trade constraints, and heightened security requirements, collectively extending construction schedules [3].

Historical examples further illustrate this relationship. The construction of Ukraine's Khmelnytskyi and Rivne nuclear power plants experienced significant delays amid the geopolitical turbulence surrounding the collapse of the Soviet Union and later regional conflicts. Similarly, armed conflicts in the Middle East have historically delayed energy infrastructure projects—including nuclear initiatives—through logistical constraints, workforce displacement, and security-related suspensions [37].

Given both the statistical evidence and extensive historical documentation of conflict-induced disruption, armed conflict is retained as a high-impact indicator within the MAPSS framework. Its capacity to halt work, sever supply chains, or necessitate extraordinary security measures justifies its weighting as a critical component of national stability assessment for nuclear construction projects.

Combined effects on Model Interpretation

The multiple linear regression analysis confirmed that not all variables exert independent effects when considered simultaneously. The overall model was statistically significant indicating that approximately 26.6% of the variance in construction duration can be explained by the combined macroeconomic and political stability indicators. Notably, national economic crises and government collapse emerged as the most significant predictors of prolonged construction durations.

Variables that were significant in the bivariate analyses—such as GDP growth, unemployment, and armed conflict—did not achieve significance in the multivariate model, suggesting that their effects may be mediated through or overshadowed by crisis-level disruptions. This finding reinforces the conclusion that acute destabilizing events, rather than gradual economic trends, are among significant drivers of large-scale construction delays [38,39].

MAPSS Index and Practical Implications

The statistically significant correlation between the MAPSS score and construction duration ($r = -0.390$, $p < 0.001$) provides preliminary empirical support for the conceptual validity of this composite index. MAPSS integrates a broad range of macroeconomic and political indicators—continuous measures such as GDP growth and unemployment, together with discrete, event-based risks including economic crises, government collapses, and armed conflicts—into a single stability metric. The negative relationship between MAPSS and project duration indicates that lower national stability scores are associated with longer nuclear power plant construction periods. Although the index explains approximately 15% of the variance in project duration, its performance surpasses that of any single constituent variable, suggesting initial predictive relevance.

MAPSS is intended primarily as an early-stage screening tool for assessing macroeconomic and political risks in nuclear infrastructure projects. It offers decision-makers an objective measure of whether a host country's stability conditions are conducive to successful project execution and can help identify areas where systemic risks require mitigation. By consolidating both structural and event-based risk factors, the MAPSS framework enables transparent risk communication and informed decision-making at the national or intergovernmental level. Even in contexts where projects proceed under suboptimal stability conditions, MAPSS can assist stakeholders in prioritizing mitigation strategies and contingency planning. This aligns with emerging research that integrates composite indices and multidimensional metrics for evaluating systemic risk in infrastructure delivery. Recent frameworks for infrastructure-risk quantification and resilience modelling likewise highlight the value of aggregated indicators for early-stage decision support [40]. Furthermore, the development and application of advanced composite indexing have become a proven methodological standard for comprehensively measuring complex socio-economic parameters, regional development, and national sustainability statuses [41]. Such approaches collectively strengthen the rationale for adopting MAPSS as a standardized screening tool in the nuclear domain.

Limitations and Future Research

This study is subject to several limitations. While the dataset of 96 nuclear power plant projects was carefully compiled and stratified, it represents only a subset of the global fleet. Data availability constrained the inclusion of some projects, particularly in countries with limited transparency or incomplete historical records. As a result, certain geographic regions or political contexts may be underrepresented.

The analysis employs primarily linear modelling techniques. While this approach is appropriate for the study's objectives, more complex methods — including nonlinear models, machine learning algorithms, or stochastic simulations — could be explored in future studies to capture potential interaction effects between variables and improve predictive accuracy.

Future research could also refine and validate the MAPSS framework by testing it against other types of infrastructure megaprojects beyond the nuclear sector, such as renewable energy, transportation, or defence projects. Additionally, longitudinal studies examining how stability conditions evolve throughout the full lifecycle of a project — from planning to commissioning — could offer deeper insights into risk dynamics.

CONCLUSION

This study provides empirical evidence that national macroeconomic and political stability is a material determinant of nuclear power plant (NPP) construction duration and should be treated as a core schedule-risk domain rather than a background contextual condition. Using a stratified sample of 96 reactor projects and complementary bivariate and multivariate tests, the analysis shows that destabilizing shocks—especially national economic crises and severe political disruption—are associated with systematically longer delivery timelines. These results reinforce the view that nuclear new-build performance is shaped not only by project-internal capabilities and regulatory processes, but also by the macro-institutional environment that conditions financing continuity, industrial capacity, supply-chain reliability, and governance stability over extended delivery horizons.

A central contribution of the paper is the development and validation of the Macroeconomic and Political Stability Score (MAPSS), a composite index that integrates continuous economic indicators with low-frequency, high-impact political and crisis events. MAPSS demonstrates a statistically significant association with construction duration ($r = -0.390$, $p < 0.001$) and explains more variance than any single constituent indicator, indicating that the stability environment is better captured as a multidimensional construct than through isolated macroeconomic metrics. While MAPSS is not intended to function as a deterministic forecasting model, its explanatory performance is meaningful in the context of infrastructure megaproject research, where outcomes are typically driven by multicausal and interacting factors. In this setting, even moderate macro-level explanatory power represents substantive insight, because it isolates a systemic layer of risk that is often omitted from conventional project appraisal and schedule-risk baselines.

The findings have direct implications for nuclear investment governance. Because nuclear projects are highly capital intensive, long-duration, and path dependent once construction begins, exposure to instability-related shocks has asymmetric consequences: disruptions can propagate through financing structures, contracting regimes, labour availability, and international supply chains, amplifying delay effects and increasing the probability of schedule collapse. MAPSS offers a transparent and replicable mechanism for incorporating this exposure into early-stage screening, enabling policymakers, investors, and planners to differentiate between host-country contexts where schedule risk is structurally elevated versus those where delivery conditions are comparatively resilient. In practical terms, MAPSS can support portfolio-level siting decisions, the calibration of contingency allowances, and the design of governance safeguards (e.g., staged commitments, enhanced contractual protections, resilience-oriented procurement strategies, and political-risk mitigation instruments).

At the same time, the results should be interpreted as complementary to—rather than substitutive of—project-level explanations. The model explains a substantive but partial share of variance in construction duration, consistent with the established multilevel nature of nuclear project performance. This underscores the need for future research that integrates macro-institutional indicators with project-internal variables (e.g., reactor type, delivery model, supply-chain localization, regulatory regime maturity, and owner/contractor experience), and that tests nonlinearities and interaction effects under compound crises. Further validation on larger samples and across other long-duration infrastructure sectors would also clarify the generalizability and boundary conditions of MAPSS as a stability-risk screening framework.

In conclusion, the study advances nuclear project management and megaproject research by quantifying the macroeconomic and political stability environment as a measurable risk domain and by demonstrating its systematic association with construction duration. By operationalizing national stability conditions into MAPSS, the paper offers a replicable tool and an extended explanatory lens for understanding why delivery performance diverges across countries even under broadly similar technological and regulatory demands. Embedding macro-institutional risk screening within nuclear project appraisal can therefore improve the realism of early schedule baselines, strengthen governance design, and reduce the likelihood that strategic nuclear investment decisions are made without explicit recognition of the stability conditions required for timely delivery.

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