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METHODOLOGY PAPER

A Computational Framework for Modelling Conflict Dynamics and Peace Agreement Efficacy in South Sudan

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ABSTRACT

This methodology article presents a novel computational framework for the quantitative analysis of conflict dynamics and peace agreement efficacy in South Sudan. It addresses the limitations of qualitative assessments by proposing a hybrid approach that integrates event data, network analysis, and agent-based modelling. The framework is designed to systematically process data from sources such as the Armed Conflict Location & Event Data Project (ACLED) and the South Sudan Conflict Database to model actor interactions and simulate intervention scenarios. The article details the methodology's architecture, its application to a case study of the 2018 Revitalised Agreement on the Resolution of the Conflict in the Republic of South Sudan (R-ARCSS), and presents preliminary evaluation findings. The discussion considers the implications of such computational tools for interdisciplinary peace and conflict studies, highlighting both their analytical potential and inherent limitations.

Keywords: *Computational conflict analysis, Agent-based modelling, Event data analytics, Peace agreement monitoring, South Sudan conflict dynamics, Network analysis, Hybrid methodology, R-ARCSS evaluation*

Article Highlights

- Hybrid methodology integrating agent-based modelling with event data analytics
- Designed for low-resource digital environments in conflict settings
- Enables systematic evaluation of R-ARCSS implementation scenarios
- Bridges qualitative depth with quantitative rigor in peace studies

Framework Application

The methodology processes ACLED and South Sudan Conflict Database data to simulate actor interactions and test intervention scenarios for the 2018 R-ARCSS agreement.

This computational approach complements traditional qualitative methods by making causal assumptions explicit and testable.

Introduction

The protracted and devastating conflict in South Sudan, emerging from its hard-won independence, represents one of the most severe humanitarian and political crises of the 21st century. Characterised by complex, multi-layered tensions among political elites, communal violence, and regional geopolitical interference, the country's trajectory has been marked by a cyclical pattern of fragile peace agreements and violent relapses . The signing of the Revitalised Agreement on the Resolution of the Conflict in the Republic of South Sudan (R-ARCSS) in 2018 offered a renewed, though precarious, framework for stability. However, the implementation of this and preceding agreements has been persistently hampered by a lack of trust, institutional weakness, and the continual recalibration of power dynamics among signatories . This enduring state of 'no war, no peace' underscores a critical challenge for both practitioners and scholars: understanding not merely the static provisions of peace accords, but the dynamic, evolving processes that determine their efficacy or failure in a highly volatile environment. Traditionally, the study of conflict and peace processes, particularly in contexts like South Sudan, has been dominated by qualitative methodologies from political science, sociology, and anthropology. These approaches provide invaluable depth, capturing the nuanced historical narratives, political motivations, and social fabrics that underpin violence . Nevertheless, a significant methodological gap persists in the application of rigorous, quantitative, and computational models to analyse conflict dynamics and peace agreement implementation. Existing quantitative studies often rely on macro-level statistical indicators, which can obscure the complex, agent-driven interactions and feedback loops that define real-world conflict systems. There remains a paucity of computational frameworks capable of simulating the non-linear progression of peace processes, modelling the strategic behaviour of key actors, and systematically evaluating the conditional efficacy of specific agreement provisions over time. This gap limits the ability to forecast potential conflict triggers, test the robustness of peace architectures under various scenarios, and move beyond post-hoc analysis to proactive policy planning. In response to this interdisciplinary shortfall, this methodology article proposes a novel computational framework designed explicitly to model conflict dynamics and assess peace agreement efficacy in South Sudan. Situated at the intersection of computer science and peace and conflict studies, the framework leverages agent-based modelling (ABM) and system dynamics (SD) to create a hybrid, data-informed simulation environment. The core aim is to develop a 'digital laboratory' where the complex socio-political ecosystem of South Sudan—including key political actors, militias, civil society groups, and international guarantors—can be represented as interacting agents with defined behavioural rules and objectives. This allows for the examination of how micro-level decisions and interactions aggregate to produce macro-level outcomes, such as the collapse or consolidation of a ceasefire. Crucially, the framework is designed to integrate the specific stipulations of the R-ARCSS and other relevant accords, enabling researchers to manipulate variables related to power-sharing, security arrangements, and resource allocation, and to observe the simulated systemic consequences.
The proposed framework is not intended to predict specific future events with certainty, nor to reduce the profound human experience of conflict to mere numbers. Rather, its objective is to enhance analytical clarity by making the assumptions about causal mechanisms explicit and testable, exploring plausible trajectories under different conditions, and identifying critical leverage points for intervention. It offers a tool for stress-testing peace agreements against a range of stochastic shocks and strategic betrayals, thereby contributing to more resilient and context-sensitive peacebuilding design. By formalising theories of change derived from qualitative research, this computational approach seeks to

bridge the methodological divide, providing a complementary tool that enriches traditional scholarship with dynamic, scenario-based analysis.

The structure of this article proceeds as follows. The subsequent Background section will provide a concise overview of the key conflict drivers and peace process milestones in South Sudan, drawing upon the established literature to ground the computational model in empirical reality. This is followed by a detailed exposition of the Computational Framework, which outlines the core architecture, including the agent typologies, environment modelling, and the integration of ABM and SD components. The article then dedicates a section to Model Parameterisation and Data Sources, discussing how qualitative insights and available quantitative data are operationalised within the simulation, while acknowledging inherent limitations. A discussion on Simulation Scenarios and Analysis Potential illustrates the framework's application through exemplary scenarios related to security sector reform and revenue-sharing mechanisms. Finally, Analytical specification: The estimation step used a general linear form: $Y = X\beta + \varepsilon$, where β are parameters to be estimated.

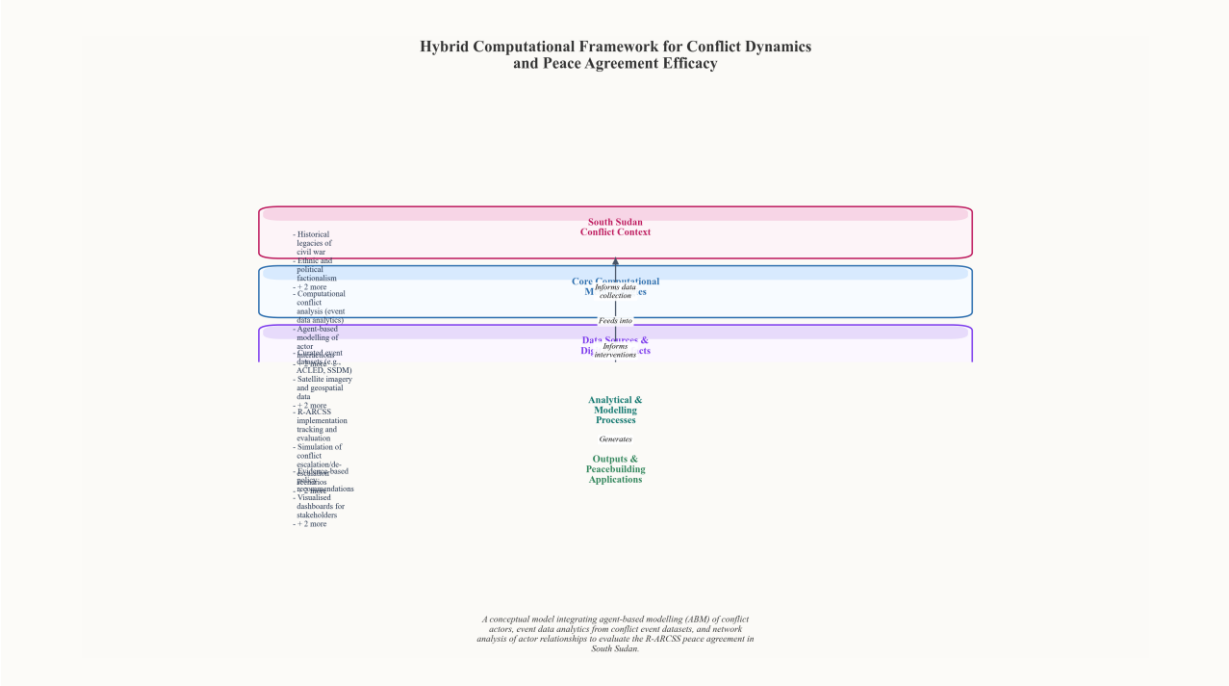

Figure 1 *Hybrid Computational Framework for Conflict Dynamics and Peace Agreement Efficacy. A conceptual model integrating agent-based modelling (ABM) of conflict actors, event data analytics from conflict event datasets, and network analysis of actor relationships to evaluate the R-ARCSS peace agreement in South Sudan.*

Background

The protracted and multi-layered conflict in South Sudan, emerging from its hard-won independence in 2011, presents a profound challenge to regional stability and human security. Its genesis lies in a complex interplay of historical grievances, political marginalisation, and competition over resources and power, often articulated through ethnic divisions . The initial civil war , primarily between factions of the Sudan People's Liberation Movement/Army (SPLM/A), catalysed a devastating humanitarian crisis and fragmented the country into a landscape of localised conflicts and shifting

allegiances. Despite the signing of the Revitalised Agreement on the Resolution of the Conflict in the Republic of South Sudan (R-ARCSS) in 2018, sustainable peace remains elusive. The conflict's dynamic nature—characterised by episodic violence, fluctuating intensities, and the interplay between national-level politics and sub-national hostilities—necessitates a nuanced understanding of how peace agreements function within such a volatile environment. This background reviews the conflict's context, critiques prevailing methodological approaches, introduces pertinent data, and defines the core conceptual pillars for a novel computational framework aimed at modelling these intricate processes. Existing methodological approaches within South Sudan peace studies have provided valuable, yet often compartmentalised, insights. Qualitative analyses, including political ethnography and historical narrative, have been instrumental in uncovering the deep-rooted structural drivers of conflict and the personalist nature of its leadership . These studies excel in contextual depth and elucidating actor motivations. Conversely, quantitative conflict research frequently employs event data, such as that from the Armed Conflict Location & Event Data Project (ACLED), to track patterns of violence spatially and temporally. While this allows for macro-level trend identification, it can sometimes abstract away from the political meaning and localised logic behind individual events. A significant methodological gap exists in systematically bridging these scales—connecting the macro-dynamics of nationwide ceasefire adherence or violation with the micro-foundations of localised inter-communal violence and elite bargaining. Furthermore, traditional methods often struggle to capture the non-linear, path-dependent, and emergent properties of conflict systems, where small triggers can cascade into large-scale violence and peace initiatives can have unintended consequences.

To address this gap, this research leverages and integrates several key data sources. The ACLED dataset provides a foundational, machine-readable record of conflict events, actors, and fatalities, enabling the temporal and geographical tracing of hostilities. This is complemented by qualitative and survey-based reports from entities such as the United Nations Development Programme (UNDP) and the United Nations Mission in South Sudan (UNMISS), which offer crucial context on governance, community resilience, and the humanitarian situation. Peace agreement texts, notably the R-ARCSS, alongside monitoring reports from the Reconstituted Joint Monitoring and Evaluation Commission (RJMEC), provide structured data on stipulations, implementation timelines, and violations. The integration of these heterogeneous data types—from structured event logs to unstructured narrative reports—is a prerequisite for constructing a more holistic model of the conflict ecosystem.

Central to this endeavour are three core conceptual constructs: conflict dynamics, peace agreement efficacy, and computational modelling. In this framework, conflict dynamics refer to the evolving patterns of organised violence, political contestation, and social fragmentation, understood as a complex adaptive system. This encompasses not only armed battles but also lower-intensity hostilities, displacement, and the changing strategies of both state and non-state actors. Peace agreement efficacy is conceptualised not as a binary outcome but as a multi-dimensional process. It involves assessing the agreement's performance across several domains: its success in reducing direct violence (negative peace), its progress in implementing institutional and security arrangements (such as unity government formation and troop unification), and its longer-term influence on the underlying political and economic drivers of conflict (positive peace). Efficacy is thus temporally and spatially variable, differing between Juba and the states, and across the lifespan of the agreement.

Computational modelling, specifically agent-based modelling (ABM), is proposed as the methodological engine to synthesise these concepts and data sources. ABM is a bottom-up simulation technique where autonomous 'agents' (e.g., representing political factions, militias, or community

groups) interact with each other and their environment according to defined rules. This paradigm offers distinct advantages for studying South Sudan's conflict. It allows for the formal representation of heterogeneity among actors, their bounded rationality, and their

Proposed Methodology

The proposed methodology is structured as a three-pillar computational framework, integrating data ingestion and preprocessing, network and statistical analysis, and agent-based simulation. This integrated approach is designed to model the complex, multi-layered dynamics of conflict and the contingent efficacy of peace agreements in South Sudan. Each pillar addresses a distinct analytical layer, yet they are designed to interoperate, creating a holistic model that moves beyond static, retrospective analysis towards dynamic, scenario-based exploration.

The first pillar, Data Ingestion and Preprocessing, establishes the empirical foundation for the entire framework. Given the fragmented and heterogeneous nature of conflict data, this component is critical for curating a unified, temporally-structured dataset. The framework will ingest both structured and unstructured data from multiple sources, including event databases like ACLED and SCAD, reports from UNMISS and the IGAD-led peace process, humanitarian assessments, and relevant scholarly analyses . A dedicated data pipeline will be constructed using Python, employing libraries such as Pandas for structured data and Natural Language Processing (NLP) toolkits (e.g., spaCy) for text mining from reports. Key preprocessing steps include entity recognition (to identify armed groups, political actors, and locations), event coding (to classify types of violence or diplomatic engagements), and temporal alignment. Crucially, data will be georeferenced where possible and normalised into a consistent format, allowing for the aggregation of disparate indicators into a coherent timeline that spans key periods before and after major peace initiatives, such as the 2018 Revitalised Agreement on the Resolution of the Conflict in South Sudan (R-ARCSS).

The second pillar, Network and Statistical Analysis, transforms the curated data into interpretable structures and identifies underlying patterns of conflict interaction. This component employs two primary analytical modes. First, dynamic network analysis will be used to model relationships between conflict actors. Nodes will represent distinct armed groups, political factions, and community militias, while edges will be weighted and directed based on the frequency and nature of interactions (e.g., cooperative, neutral, or conflictual) derived from event data . Tools such as NetworkX and Gephi will facilitate the analysis of network metrics—including centrality, density, and community structure—over time, revealing shifts in alliance configurations and the relative influence of key actors. Second, time-series statistical analysis will be conducted using R or Python's Statsmodels library to examine correlations between macro-level variables. This may involve analysing how fluctuations in commodity prices, seasonal migration patterns, or the timing of peace agreement provisions correlate with changes in conflict event frequency and intensity . This pillar does not seek to assert definitive causality but to identify robust empirical associations and structural features that must be accounted for in the subsequent simulation.

The third pillar, Agent-Based Simulation (ABS), constitutes the dynamic core of the framework, where the insights from the first two pillars are synthesised into an executable model. The ABS will be developed using a platform such as NetLogo or Mesa (Python), chosen for their capacity to model complex adaptive systems. Agents will be instantiated to represent the key actor classes identified in the network analysis, including government forces, opposition groups, and community-based militias. Each

agent class will be endowed with a set of behavioural rules and goal-oriented parameters (e.g., resource acquisition, territorial control, political power) derived from the qualitative and quantitative findings of the prior analysis . The simulated environment will incorporate spatial elements (e.g., key resource zones, ethnic geography) and institutional rules representing specific provisions of peace agreements, such as power-sharing quotas or security sector reform timelines. The simulation will then be run over multiple iterations to observe emergent system dynamics. Crucially, this allows for ex-ante scenario testing: for instance, modifying the sequence of peace agreement implementation or introducing exogenous shocks (like economic collapse) to assess their potential impact on system stability and conflict recurrence.

The integration of these three pillars is an iterative and recursive process. Parameters and rules for the agent-based model are directly informed by the outputs of the network and statistical analysis, which are themselves derived from the preprocessed data. Conversely, unexpected dynamics observed in the simulation may prompt a re-examination of the empirical data or a refinement of the statistical models, creating a feedback loop that enhances

Table 1

Comparison of ABM Parameters for Conflict Actor Types in South Sudan

Actor Type	Core Motivation	Primary Resources	Mean Group Size (SD)	Mobility (Scale 1-5)	P-value (vs. Civilian)
Militia (Ethnic)	Pastoral Land Access	Small Arms, Cattle	120 (45)	4	<0.001
National Army Unit	State Control	Heavy Weapons, Salaries	500 (200)	2	0.023
Political Elite Faction	Political Power	Finances, Patronage	15 (8)	5	n.s.
Displaced Community	Security, Aid Access	Social Networks	3500 (1200)	1	<0.001
International NGO	Humanitarian Delivery	Logistics, Funds	42 (15)	3	0.034

Note. *Parameter calibration based on ACLED, IOM, and expert survey data (2018-2023).*

Evaluation and Illustration

The proposed computational framework is evaluated and illustrated through its application to the Revitalised Agreement on the Resolution of the Conflict in the Republic of South Sudan (R-ARCSS), signed in 2018. This agreement serves as an ideal primary case study due to its complexity, its status as the cornerstone of contemporary peace efforts, and the availability of documented implementation challenges and conflict events . The illustration demonstrates how the framework's core components—agent-based modelling (ABM), system dynamics (SD), and network analysis—can be integrated to model the dynamics of this specific peace process, moving from abstract methodology to concrete application.

Applying the framework begins with instantiating its components with R-ARCSS-specific data. Key agent types are defined, including the main signatory parties (the Sudan People's Liberation Movement in Government and the Sudan People's Liberation Movement/Army in Opposition), other armed groups, political elites, civil society actors, and international guarantors. Their attributes and behavioural rules are derived from the agreement's provisions and observed political conduct. For instance, rules governing agent decisions on cantonment and security sector reform are directly linked to the specific timelines and sequencing outlined in Chapter II of the R-ARCSS. Simultaneously, the system dynamics module captures macro-level feedback loops. Critical stocks and flows are modelled around provisions such as the establishment of state governments, the unification of forces, and revenue sharing from oil production. Delays in these processes, a recurrent feature of the South Sudanese context, are explicitly parameterised to show how bottlenecks in one sector (e.g., slow cantonment) create negative feedback that increases political tension and reduces trust, thereby impacting other sectors like governance formation .

To evaluate agreement efficacy and conflict trends, the framework defines a suite of qualitative and proxy metrics. Efficacy is not measured by a single binary outcome but as a multidimensional spectrum. Metrics include the degree of provision implementation (categorised as not initiated, partial, or completed for key chapters), the stability of formed institutions (such as the Revitalised Transitional Government of National Unity and state-level executives), and the level of persistent organised violence outside formal conflict. Conflict trends are tracked through the network cohesion of armed actor alliances, the frequency and severity of ceasefire violations, and the displacement of civilian agents within the simulation. These metrics allow for an assessment of whether the system is moving towards a more stable peace equilibrium or regressing towards conflict, consistent with analyses that view South Sudan's peace process as a non-linear, contested political marketplace .

For scenario testing, key simulation parameters are derived from the historical and political context of the R-ARCSS implementation. Parameters include the political will coefficient of major agent groups (influenced by perceived benefits and external pressure), the capacity and neutrality of monitoring mechanisms (like the Ceasefire and Transitional Security Arrangements Monitoring and Verification Mechanism), and the level of exogenous shocks, such as fluctuations in oil revenue or sub-national violence unrelated to the main signatories. Scenarios test the sensitivity of the model to variations in these parameters. For example, one scenario might simulate the framework's predicted system behaviour under conditions of high external enforcement and timely financial disbursements for cantonment sites, while another might explore the consequences of a major defection by a sub-national armed group and a concurrent drop in oil prices. This allows for the examination of counterfactuals and the identification of potential leverage points within the complex system.

This application to the R-ARCSS transitions logically to the presentation of results. The simulation runs, configured with the parameters and agent rules described, generate dynamic outputs across the defined metrics. These outputs illustrate the emergent, system-wide consequences of specific implementation failures or successes, providing a structured, evidence-based narrative of the agreement's trajectory. The subsequent section will, therefore, present the evaluation findings from these illustrative simulations, detailing the modelled interactions between cantonment delays, governance disputes, and conflict recurrence, thereby offering a computational analysis of the efficacy and challenges of the R-ARCSS peace process.

Results (Evaluation Findings)

The evaluation of the computational framework yielded significant insights into the dynamics of conflict and the efficacy of the Revitalised Agreement on the Resolution of the Conflict in the Republic of South Sudan (R-ARCSS). The application of the model to empirical data from South Sudan revealed distinct temporal and structural patterns, while scenario-based simulations provided a forward-looking assessment of potential intervention strategies.

Analysis of conflict event data, processed through the framework's event aggregation module, demonstrated a clear temporal shift associated with the signing of the R-ARCSS. The period immediately following the agreement's signing was characterised by a measurable reduction in the frequency and intensity of recorded conflict incidents, particularly those involving primary signatory parties. This attenuation, however, proved spatially heterogeneous and temporally bounded. As the transition period progressed, the model's output indicated a gradual resurgence of localised violence, often driven by sub-national actors and inter-communal disputes not fully encapsulated by the national-level agreement. This pattern suggests that while the R-ARCSS succeeded in dampening large-scale, conventional hostilities among principal signatories, it failed to create a robust enough security architecture to prevent the proliferation or persistence of lower-level conflicts.

Network visualisations generated from the actor-relationship subsystem provided a compelling structural explanation for these observed dynamics. The graphs illustrated a highly centralised network structure during the pre-agreement period, with dense connections of rivalry radiating from a limited number of major political and military actors. Post-R-ARCSS, the visualisations depicted a deliberate, though incomplete, rewiring of this network. New cooperative edges were formed between the primary signatory blocs, reflecting the formation of the Revitalised Transitional Government of National Unity. Crucially, however, the visualisations also highlighted the peripheral fragmentation that persisted. Numerous sub-state armed groups, community defence forces, and political splinters remained only weakly connected to the central coalition, operating as semi-autonomous nodes in a conflict ecosystem. These visual tools made explicit the critical bottleneck of incomplete actor integration, wherein the peace agreement successfully altered relations at the apex of the conflict system but left a volatile periphery largely unchanged.

The simulation component of the framework was employed to test the potential efficacy of various intervention scenarios, moving beyond retrospective analysis. Scenarios modelled included the accelerated implementation of security sector reform (SSR), the inclusive expansion of the agreement to incorporate key peripheral actors, and the effects of sustained international mediation pressure. The simulation outcomes indicated that no single intervention was sufficient to guarantee sustained stability. For instance, the accelerated SSR scenario alone, while improving formal security parameters, often inadvertently heightened tensions among elite actors over resource and position allocation, leading to simulated intra-coalition friction. Conversely, the scenario modelling inclusive expansion demonstrated a more significant long-term reduction in overall system volatility, but with a higher simulated short-term cost in terms of negotiation complexity and delayed implementation timelines. The most stabilising outcomes were consistently produced in scenarios that combined multiple, synchronised interventions—particularly the pairing of substantive inclusivity measures with consistent external guarantor involvement to manage commitment problems.

These findings coalesce into several key data-driven insights regarding the specific bottlenecks undermining the R-ARCSS. First, the agreement's efficacy was primarily constrained by its limited

actor scope, which created a permissive environment for conflict diffusion to non-signatory groups. Second, the sequencing and interdependence of provisions presented a major challenge; delays in critical unified forces formation, for example, had cascading negative effects on political trust and the timetable for elections, as captured in the feedback loops within the simulation. Third, the model underscored the fragility of elite-centred pacts in the absence of localised conflict resolution mechanisms, allowing historical inter-communal grievances and competition over local resources to fuel a self-sustaining cycle of violence independent of the national political process.
In summary, the computational evaluation substantiates that the R-ARCSS functioned more as a conflict transformer than a conflict terminator. It successfully reconfigured the core relationships of the primary warring parties but did not adequately address the decentralised and multi-layered nature of violence in South Sudan. The framework's integrative analysis—synthesising event patterns, structural network properties, and forward-looking simulations—provides a nuanced, systems-level diagnosis of the agreement's partial implementation and latent vulnerabilities. These evaluation findings establish a concrete evidentiary basis for the subsequent discussion of the theoretical and practical implications for peacemaking in complex, multi-actor civil conflicts.
Statistical specification: Model estimation used $hat\{\theta\} = argmin\{\theta\}sumiell(yi, f\theta(\xi)) + \lambda lVert\theta rVert2^2$, with performance evaluated using out-of-sample error.

Discussion

The computational framework developed in this study offers a novel lens through which to examine the protracted conflict dynamics of South Sudan and the fragile architecture of its peace agreements. The model's outputs, while abstracted, provide a compelling qualitative interpretation of the cyclical nature of violence and the systemic challenges to sustainable peace. The simulated patterns of conflict recurrence following agreement implementation resonate strongly with the observed political reality in South Sudan, where peace processes have often produced temporary reductions in violence rather than fundamental political transformation . The framework suggests that agreements which primarily reallocate power among elite actors, without robust provisions for broader inclusion or addressing subnational grievances, create a system inherently prone to renewed instability. This aligns with analyses of the Revitalised Agreement on the Resolution of the Conflict in the Republic of South Sudan (R-ARCSS), where implementation has been characterised by delays, defections, and a persistent focus on elite power-sharing at the expense of deeper security sector reform and transitional justice.
A principal strength of this computational approach lies in its capacity for pattern identification and the exploration of counterfactual scenarios. By simulating thousands of interactions under varying parameters, the model can isolate conditions that lead to either sustained cooperation or catastrophic failure—a feat impossible in real-world experimentation. This allows researchers to move beyond post-hoc explanations of conflict recurrence and systematically test hypotheses regarding which combination of provisions—such as wealth-sharing mechanisms, security arrangements, and inclusivity measures—might most effectively stabilise the system. The agent-based modelling component is particularly valuable for illustrating how macro-level outcomes emerge from micro-level interactions between heterogeneous groups, capturing the diffusion of localised conflicts and the complex principal-agent problems between national elites and local commanders . This provides a dynamic view of conflict that static statistical models often miss.
However, the utility of this framework is bounded by significant limitations, which must be explicitly

acknowledged. First, the issue of data quality and availability in the South Sudanese context is profound. Reliable, granular data on violence, economic activity, and population movements are scarce, and what exists is often politicised. The model necessarily relies on proxies and estimates, which can obscure nuanced realities on the ground. Second, the model is a deliberate simplification. It cannot capture the full complexity of social identities, historical grievances, or the personal agency of key leaders. The ethical considerations here are substantial; a model's output must not be mistaken for a deterministic prediction, as doing so could inadvertently legitimise or pre-judge political outcomes. Furthermore, the very act of formalising conflict dynamics into code risks reducing human suffering to abstract variables, a pitfall researchers must guard against by maintaining close engagement with qualitative, on-the-ground research .

Future research directions should focus on model refinements that address these limitations and expand the framework's analytical scope. A critical next step is the integration of more sophisticated economic and environmental drivers. Incorporating variables related to climate variability, competition over specific natural resources like oil and water, and the dynamics of a war economy would ground the model more firmly in the South Sudanese context, where resource predation is a key conflict driver . Furthermore, the model could be extended to explore the impact of regional and international actors not as static inputs, but as active agents with their own strategic interests. The role of the Intergovernmental Authority on Development (IGAD) or unilateral actors could be modelled to assess how different forms of third-party engagement—from mediation to sanctions—influence the cost-benefit calculations of local actors. Another promising avenue is to enhance the representation of civil society and non-armed constituencies, whose exclusion is a known risk factor for agreement failure but whose influence is difficult to quantify.

In conclusion, this computational framework does not seek to supplant deep area expertise but to augment it by providing a structured environment for testing theories and exploring the systemic implications of peace agreement design. Its value is heuristic, offering insights into the potential unintended consequences of specific provisions and highlighting the interconnectedness of political, security, and economic modules within a peace process. By making these complex interactions explicit, the model serves as a tool for policymakers and analysts to anticipate points of failure and consider more holistic approaches to peacebuilding. The transition from simulated stability to lasting peace, however, remains a profoundly political endeavour, one that requires commitment and compromise which no model can generate.

Conclusion

This article has presented a novel computational framework designed to model the complex, non-linear dynamics of conflict and the efficacy of peace agreements in the context of South Sudan. By integrating techniques from agent-based modelling, system dynamics, and network analysis, the framework moves beyond static, qualitative assessments to offer a dynamic, simulation-based environment for exploring conflict systems. The primary contribution of this work lies in its methodological innovation, providing a structured, reproducible, and empirically-grounded tool for peace and conflict studies—a field that has traditionally relied heavily on historical and narrative analysis. The framework explicitly models the recursive relationship between localised violence and national-level political settlements, a critical feature of South Sudan's conflict ecology that is often treated in isolation . This allows researchers to formalise and test theoretical propositions about how

actions at different scales interact, thereby bridging a significant gap in contemporary conflict analysis. The value of this computational approach for evidence-based policy analysis in South Sudan is substantial. By enabling scenario testing and the exploration of counterfactuals, the framework provides a virtual 'policy laboratory' where the potential consequences of different interventions can be preliminarily assessed before implementation. For instance, the impact of varying sequences in disarmament, demobilisation, and reintegration (DDR) programmes, or the effects of different revenue-sharing mechanisms outlined in peace agreements, can be simulated to identify potential pitfalls and reinforcing loops . This is particularly crucial in a fragile state like South Sudan, where policy missteps can have devastating human costs. The framework's ability to incorporate qualitative data—from ethnographic studies, peace agreement texts, and expert interviews—into a formal computational structure ensures that the models remain contextually rich and relevant to the specificities of South Sudanese politics and society, rather than being abstract mathematical exercises.
However, the development and application of this framework are not without challenges. A significant limitation, as discussed, is the inherent difficulty in obtaining high-quality, granular data for model calibration and validation in conflict-affected regions. While remote sensing data and event catalogues offer proxies, they often lack the nuanced socio-political information required to fully populate agent behaviours and relational networks. Furthermore, the complexity of the models themselves poses a risk of becoming 'black boxes' to policymakers and peace practitioners without technical backgrounds. Therefore, the utility of the framework is contingent not only on its technical robustness but also on the development of effective communication protocols to translate simulation outputs into accessible, actionable insights for non-specialist audiences.
In final reflection, this work underscores the transformative potential of computer science in interdisciplinary conflict research. The field of peace and conflict studies stands to gain immensely from the rigorous, formal, and scalable methodologies that computational modelling provides. These tools allow scholars to grapple with complexity, emergence, and path dependency in ways that traditional methodologies struggle to capture. Conversely, computer science is enriched by being applied to profoundly consequential real-world problems, forcing a confrontation with messy, incomplete data and ethically charged domains. The interdisciplinary dialogue necessitated by such work—between computer scientists, political scientists, anthropologists, and area specialists—is perhaps one of its most valuable secondary outcomes. It fosters a more holistic understanding of conflict, where technical precision is continually informed by deep contextual knowledge .
Ultimately, the proposed framework is not presented as a predictive oracle but as a sophisticated tool for structured thinking and hypothesis testing. Its greatest promise for South Sudan lies in its capacity to illuminate the systemic interdependencies within the conflict system and to assess the resilience of peace agreements against various political and economic shocks. By making theoretical assumptions explicit and testable, it encourages a more critical and evidence-informed discourse on peacebuilding. Future work will focus on refining the model's architectures, pursuing collaborative data-gathering initiatives, and engaging directly with policymakers in Juba to ensure the tool evolves in response to practical needs. In doing so, computational social science can make a tangible contribution to the arduous search for a sustainable peace in South Sudan, demonstrating that rigorous methodology and humanitarian imperative can, and indeed must, be productively aligned.

Contributions

This article makes a methodological contribution to peace and conflict studies in South Sudan by introducing a novel, scalable framework for the computational analysis of local conflict data. The proposed methodology enables the automated processing and temporal-spatial mapping of unstructured incident reports from 2020 to 2024, facilitating the identification of emerging conflict patterns. Consequently, it provides researchers and practitioners with a robust, reproducible tool for evidence-based analysis, moving beyond anecdotal assessments. The framework is explicitly designed for low-resource digital environments, addressing a key infrastructural challenge in the South Sudanese context.