REALLAND: A WARGAMING APPROACH TO COMPUTATIONAL INTERNATIONAL RELATIONS

by

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Dedication

I dedicate this dissertation to my wife Amy and son Ronnie for their continuous support and encouragement, to my parents for impelling me to finish for nearly a decade, and to my God who is ever faithful.

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Abstract

REALLAND: A WARGAMING APPROACH TO COMPUTATIONAL INTERNATIONAL RELATIONS

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The objective of this study is to advance a wargaming approach to computational international relations (IR). Wargaming has a long tradition of artfully balancing between realism and human playability. Those same techniques can be incorporated into computational IR models. A wargaming approach affords both greater resolution in the operational environment and emulation of human decision-making, which provides a significant alternative to past computational IR models of international conflict. As a demonstration of this approach, I developed two simulations: Basic and Enhanced RealLand.

Basic RealLand is a replication of the work of past researchers (Cusack & Stoll, 1990; Duffy, 1992) providing a comparative foundation for innovation within Enhanced RealLand. Enhanced RealLand combines computational social science (CSS) techniques with defense and commercial wargaming mechanisms to enable a wargaming approach to computational IR. It is a strategic-operational simulation where players sense the world, identify issues, develop strategies, and implement actions such as trade, alliance building, and war. The shift away from game-theoretic approaches for modeling computer agents as nation-states to the conflict-theory model as players proved promising, and the results generate a world

worthy of the prominent IR realist theorists. An important contribution is the creation of a pseudo history, similar to that of a narrative resulting from a social simulation.

This study advanced a wargaming approach to computational IR by demonstrating that additional representative modeling, in a human playable form, can be used for advanced IR research. By placing the focus on simulating human decision-making through a descriptive process, Enhanced RealLand provides an approach and extensible framework for computational IR models to have analytic utility whether for theorists, policy-makers, or educators.

Chapter 1: Introduction

1.1 Motivation: Research Questions (RQs)

> Those who say it cannot be done, should not get in the way of those who are doing it.
>
> Unknown

International relations (IR), the branch of political science where theory and research is focused on the relations between nation-states, presents significant difficulties to academic study. Perhaps the most significant difficulty is the inability to experiment with a state directly. As socially constructed entities do not exist for experimentation purposes, the IR researcher is forced to use substitution for simulation. A state must be surrogated by some combination of human decision-makers or decision-making logic, and embedded within an environment with other contrived states. The surrogates become the object of study. For social simulation, emulation of nation-states is replaced by the study of human decision-making under stimuli.

The second difficulty has to do with the limitations of social simulation. Social simulation is cost prohibitive and time limited. Participants, either amateur or professional, must commit to spending several hours or days at the event. Usually, participants engage in a single or only a few simulation iterations. Personal insights are internalized by players. Game insights are captured by the experimenter. In a well-constructed IR simulation, the cause-and-the-effect appear plausible and generalizable. During the post-event *hotwash*, participants will even draw parallels between simulation play and events in history. However, any explanatory argument, particularly induced from a single social simulation, must be made under significant uncertainty. As a result, social simulations may overrepresent the explanatory power of any single iteration (Snyder, 1963). Social simulation may be the best method for simulating IR, but its value is constrained by sheer logistics.

The third difficulty has to do with the limitations of computational IR. Computational IR may provide many iterations but there is little cause to trust the results. In the last twenty years, computational IR of international conflict has made few advancements. Most of the legacy models are very abstract exploring only factors influencing the stability of the international system and state survival within the IR realist paradigm.

Based upon this motivation, this study will address the following basic research questions:

1. *Can a wargaming approach to computational IR be used for conducting advanced IR research, where verisimilitude in detail enhances rather than detracts from the epistemological value?*[1] A wargaming approach affords greater resolution (e.g. military units, discrete resources, road networks, etc.) in the operational environment, artfully balancing between realism and human playability. Additionally, a wargaming approach to computational IR places the focus on simulating human decision-making through a descriptive process. This provides a different avenue for experimentation and study versus the rational choice theory and simple heuristics currently employed in computational IR. The construction of an analytically useful model that is simultaneously playable by humans and computer agents is the focus of this research. The quest is for parsimony where theory meets practice. Computational Social Science

[1] Verisimilitude or *truthlikeness* is a somewhat debunked concept proposed by Karl Popper as he attempted to prove that one false theory could be closer to the truth than another false theory (Johansson, 2017). For simulation-oriented disciplines, the concept is retained to distinguish balance in the quest for both simplicity and realism. A simple model is analytical, meaning the relationship between input and output is readily discernible. Regression testing on parametric analysis of the model is quite effective. As the model increases in realism, which almost always leads to a more complicated representation, the greater the verisimilitude. While models are all assumed to be pale comparisons to reality, the concept of verisimilitude suggests that simple models are paler than their more complicated cousins.

(CSS) emphasizes the study of social science through the examination of how people process information. Similarly, wargaming is a study of the consequences of decision-making. My hypothesis is that a wargaming approach to computational IR will lead to higher quality models of interstate conflict.

2. *Can agents, instantiated with a conflict-theory model of strategic decision-making, generate key behaviors consistent with realist theory?* This is a significant and uncharted departure in IR computational modeling. The conflict-theory model is a model of strategic decision-making developed by Janis and Mann (1977). I'm proposing that the agent decision-making process use a conflict-theory model as opposed to legacy implementations, such as rational choice theory. When faced with decisional conflict, an agent will apply a coping pattern to handle the psychological stress that affects the quality of the decision-making process. Decision-making is made under one of four stages of decisional conflict: unconflicted adherence, unconflicted change, vigilance, and hypervigilance. Given this new approach to modeling agent decision-making, I will examine whether the results are consistent with realist theory as espoused by Morgenthau (1973), Waltz (1979), or Mearsheimer (2014). Realism views states as the key actors in international politics existing in an anarchic system to perpetuate themselves and to dominate, or at least not be dominated by, other states. My hypothesis is that agents, instantiated with a conflict-theory model, will generate results consistent with realist theory.

3. *How does increasing the resolution of IR models affect the findings?* I am building upon a limited tradition of CSS modeling with a few pioneering models done almost 30 years ago. While some notable researchers such as Lars-Erik Cederman (1997) have extended this work through their own unique implementations, there is some value in replicating the pioneers' approaches for verification, extension, and comparative analysis. In particular, this question aims to examine the increased detail and complexity in the operational environment using the legacy agent logic of past computational IR models. My hypothesis is that incorporating wargaming mechanisms to enhance the

resolution in the operational environment will not produce the same results, and will add much needed explanatory power. The legacy models are too abstract.

To address these questions, my research plan consists of the development of two simulations, Basic and Enhanced RealLand. The first RealLand simulation, referred to as Basic RealLand, is a replication of the work of past researchers with some additional extensions. The second RealLand simulation, called Enhanced RealLand, combines computational social science (CSS) techniques with defense and commercial wargaming mechanisms to enable a wargaming approach to computational IR. Basic RealLand is used to perform the same experiments and regression analyses as previous scholars. The results are then compared and analyzed against the previous work. As a new approach to computational IR, Enhanced RealLand is a proof of principle intended to address the research questions. For this research, the computational model itself is the main result and its evaluation answers the first two research questions. The third research question combines the operational environment afforded in Enhanced RealLand with the agent logic in Basic RealLand. A test is performed to examine the main output of international system stability in comparison to past work.

Table 1.1: Computational IR Models of International Conflict

Model	Contribution	Publication
Machiavelli in Machina	Illustrative	Bremer & Mihalka (1977)
EARTH	Analytical	Cusack & Stoll (1990)
Concurrent EARTH	Exploration	Duffy (1992)
Emergent Polarity Model	Alternative	Cederman (1997)
EARTH with Trade	Extension	Min (2002)
Paths to Great Power War	Focus Shift	Luteijn (2015)

By examining prior computational IR models, shown in Table 1.1, inspiration was gleaned for further enhancements or originality. Basic RealLand was constructed based upon the scholarship beginning with the pioneering work of Bremer and Mihalka's *Machiavelli in*

Machina (1977). Basic RealLand replicates the results Cusack and Stoll's Exploring Alternative Realpolitik THeses (EARTH) model (1990) with some attention paid to Gavan Duffy (1992) and Byoung Won Min's (2002) extensions.[2] These researchers adopted the basic structure of Bremer and Mihalka's model and analytically explored the results with the tremendous increase in computing power that occurred between 1977 and 2006. More recent works, in this niche focus of computational IR of international conflict, were rare but lucrative. Roderick Luteijn (2015) developed a computational IR model to explore the path to war between great powers. Luteijn's agent-based model had some similarities to EARTH though it was more representational. Stoll (2016) was also very responsive to inquires of any other work done in this area confirming that I had found all known work from his perspective.

Basic RealLand was developed based upon the available EARTH documentation and programmed within the NetLogo agent-based modeling (ABM) environment (Wilenksy, 2017). Familiarization with modeling state actors through the replication of past work proved productive. Basic RealLand generates empirically-free abstract worlds useful for parametric testing to gain insights into broad IR concepts. The experiments are meticulously generated to approximate the tests of previous researchers. Through replication, it was easier to interpret other modeling attempts. For instance, the work of Girardin and Cederman (2007) with their emergent polarity model, renamed GeoSim, became far more accessible. As did Guetzkow's (1963) inter-nation simulation, which provided critical inspiration for linking domestic and international considerations. Through the successful replication of past efforts, Basic RealLand laid the foundation for the development of Enhanced RealLand.

Enhanced RealLand was developed in an attempt to better instantiate the operational environment as described by IR realist theory. With respect to Morgenthau, Waltz, Mearsheimer, and other IR theorists, there is difficulty in translating the findings of very abstract cellular

[2]My intention was to completely replicate the work of Byoung Won Min, but shifted to Enhanced RealLand instead. Much of the integration into Basic RealLand has been completed.

automata models to their descriptions of the real world. While a discussion of a grid cell contained by surrounding grid cells could have parallels to the United States policy of containment of communism in the Truman Doctrine, the intellectual reach is too far. Agents are little more than savages holding clubs that, when given the chance, will smash their neighbors. Even the crudest interpretation of Morgenthau's political realism shows Basic RealLand as a poor reflection of the envisioned international system. On the other hand, Basic RealLand is sufficiently complicated so as to lose much of the explanatory power driven from simplicity. The elegance present in Axelrod's (1984) game theoretic experiments on the iterative prisoner's dilemma or Schelling's (2006) segregation model is not realized in Basic RealLand. What good are the results of a model too complex to be understandable and too abstract to be useful? Bremer (1989) discusses the evolutionary progress in the field of world modeling as a progression from highly abstract to more realistic and complex. As the scale and resolution increases, an impasse occurs as the quest for more representation leads to opaque, unwieldy models.

Enhanced RealLand utilizes wargaming mechanisms to navigate these dimensions. Leveraging work from both social simulation and wargaming traditions of IR simulation, Enhanced RealLand constructs a realistic world with discrete military units that are employed by the agents at the strategic-operational level of war. In so doing, the researcher and computer agents can engage in a simulation that is far more emulative than available approaches. The results proved promising in that verisimilitude in detail can be incorporated without detracting from the usability of the simulation.

A key issue with the modeling of IR is that of information processing. Who and what are the agents supposed to represent and how do they process information? In Basic RealLand, state-level agents can have one of several decision-making paradigms based upon realist theory. States perceive their local neighborhood and, depending upon the imbued decision-making paradigm, they react a certain way with procedural rationality. Given the data they have available and their information processing capability, they will make the same decision. If the information turns out poor or their information processing is too simple, the decision may prove a bad one. An agent usually has one information processing system, such as satisficing, optimizing, or a simple heuristic as its mechanism to decide what to do with the information. Noise may be added into agent perception to create mistakes, but what if a state's decision-making process itself could change? What if the situation could affect how the state processed the information? Could state agents experience decisional conflict that leads to either greater or weaker information processing? What if states behaved a bit more human? What if they became players within the simulation as humans do when they engage in social simulations and wargames? What if under some conditions they satisfice and under others, they optimize?

A wargaming approach shifts the focus of agent logic to a descriptive model of human decision-making. Janis and Mann (1977) developed a conflict-theory model of strategic decision-making that is well suited for instantiation in an ABM. In Enhanced RealLand, agents engage in a desk clearing process where, depending upon the decisional conflict regarding the issue, different decision-patterns will result. An agent may satisfice in one instance, fail to respond in another, or try to maximize across the available options. This is a distinct departure from past approaches and a necessary addition for a wargaming approach to computational IR. Chris Crawford developed *Balance of Power*, a decades old computer game on international politics. He spent considerable effort attempting to calculate a player's reactions to a policy. He argued that interaction's highest form is anticipation. If the game can forecast a player's response, it can provide a more interesting result. In his research for the computer game, he noted that decision-makers spend considerable effort anticipating what the other side is going to do and what do in response (Crawford, 1986, p. 211-240). According to the conflict-theory model, this is only sometimes true. There is a place for rashness and apathy within the simulation of nations (Clausewitz, 1832). In social simulation, the practice is to position players within a rich environment to face personally consequential decisions where they have to live with the consequences. This immersion evokes a psychological response that is necessary to approximate strategic decision-making (Janis & Mann, 1977; Guetzkow, 1963). The strategic decision-maker is concerned with maintaining his domestic political power in addition to serving his state's national interests. Enhanced RealLand was constructed with this concept as a guidepost for the computer agents.

Ultimately, the pursuit of IR simulation is the coalescence of human ingenuity and computing power in the discovery of possibilities. My final contribution was the preliminary conceptualization of a new model for future study, called Interactive RealLand, where human players are agents within the simulation. For the last ten years, the Office of the Secretary of Defense has been developing the Standard Wargame Integration and Facilitation Tool (SWIFT) (Ellerbe et al., 2016). SWIFT is intentionally designed to support man-machine simulation through a combination of manual and computer-assisted means. Interactive RealLand can be constructed within the SWIFT environment augmented by plug and play adjudicators to handle the Enhanced RealLand algorithms. This model provides the ability to harness both social simulation and computational IR in a seamless fashion. Interactive RealLand would serve as a decision-aid for policymakers to explore strategic options. An insightful test of a particular contemplated strategy is a simulated application. Only three things can occur through the application of a new strategy: the situation can improve, the situation can deteriorate, or the situation can remain unchanged. However, an incomplete search of the potential outcomes under various feasible strategies can be disastrous. A wargaming approach to computational IR emphasizes capturing both the rich simulation of human players and the sheer volume of games executed by computer counterparts. A human agent may see a relationship and take action within a social simulation that the modeler would not have envisioned. Holistically, the approach would provide value as a tool for IR theorists and policy-makers that is not easily available for advanced IR research and strategy development.

In summary, I explore the utility of a wargaming approach to computational IR, examine the interactions of states through a conflict-theory driven lens, and independently verify, extend, and compare my new results with the results of past researchers. Additionally, the wargaming approach to computational IR enables the use of social simulation as a complementary tool. Due to the enhanced realism, IR experts and policy analysts can participate as agents within the simulated environment. A researcher armed with both the results of a few social simulations and extended analytic exploration (thousands of computer simulated runs) has a rich basis for making sense of possibilities and exploring hypothetical situations. IR research is not just about theory verification through empirical research, but discovery of new theories and course of action analysis.

1.2 Literature Review: Computational IR Models of Interstate Conflict

> *Computational social science is defined as the interdisciplinary investigation of the social universe on many scales, ranging from individual actors to the largest groupings, through the medium of computation.* (Cioffi-Revilla, 2014, p. 2)

Claudio Cioffi-Revilla's definition of CSS emphasizes social agents and social interactions. Cioffi (2014) argues that CSS is based upon an *information-processing paradigm.* For ABM, a major component of CSS, this is most definitely true. Computational social scientists use ABM, a type of machine-only simulation, as a medium for formal experimentation. Situated with an artificial environment, agents must sense, deliberate, and act. In positioning computer agents in the role of strategic decision-makers, this seems an appropriate pairing. This section will discuss the role of computer simulation in IR research.

Constructive or machine-only simulations of international conflict were first developed during the 1950s-1970s, with works such as Oliver Benson's (1961) Simple Diplomatic Game and Urs Luterbacher's (1979; 1985) SIMPEST. The field evolved with the work of Stuart Bremer and Michael Mihalka (1977) applying cellular automata simulation to IR research and theory testing. Cellular automata is an ABM approach that simulates agents in local neighborhoods in a two-dimensional grid. Developed as a thought experiment, these early pioneers sought to discern whether a multi-state system could persist as a function of self-interested, primitive states. If not, they thought to consider the degree to which individual states must consider the survival of the multi-state system in their decision logic. Additionally, they were particularly interested in how power perception impacted state survival and the endurance of a multi-state system. While they did not pursue rigorous analytic insights, their general model structure and research agenda fueled several researchers over the following decades.

In the 1980s, the Bremer-Mihalka model was reconstructed and extended by Thomas Cusack and Richard Stoll (1990) in the EARTH (Exploring Alternative Realpolitik THeses) model. While this stochastic conflict simulation built upon the simple agent rules and local interactions espoused by its forerunner, Cusack and Stoll also followed Bremer and Mihalka's road map for future research. The model was enhanced to include more expansive and sophisticated decision-making processes and the analysis focused on testing many of the variables discussed in the original work. An enhancement was the incorporation of civil war as a constraint on empire building which was not considered in the Bremer-Mihlka model. Following an analytical framework, Cusack and Stoll (1990) focused on the following questions:

> *Why do individual states behave the way they do? What strategies enhance or minimize their success in international politics? What accounts for the basic character and dynamics of the interstate system?* (p. 20-21)

Their approach evaluated realist theories in empirically-free scenarios making no claim their model represented the real world, but rather that it facilitated exploration in the logic of realist thought. They concluded a need to revisit realist claims, such as the significance of initial power distribution as a factor in system tranquility, the role of restraint in power politics, accuracy of state assessments of other states in generating wars, impact of the destructiveness of war and relative losses in wars on system endurance, and many others. Shortly after Cusack and Stoll's published work, Gavan Duffy (1992) tested the effects of serial assumptions within EARTH by re-implementing the model in a parallel environment.[3] In opposition to EARTH, Duffy's analysis showed that lower war costs, more decisive outcomes, greater power disparity, and higher disparities of war costs between victors and losers all positively contribute to system endurance.[4]

The 1990s witnessed the emergence of agent-based CSS and the evolution of computational techniques. Joshua Epstein and Robert Axtell (1996) demonstrated the ability of the computer model to explore fundamental micro interactions and emergent macro behaviors. Their synthetic laboratory experimented with micro rules of social and environmental interactions, incorporating procreation, culture, conflict, trade, disease, and many other factors while observing the impact on emergent macro behaviors. Specifically, conflict was modeled by several different agent interaction rules allowing agents to attack less prosperous members of different tribes within their field of vision. The consequences of aggressor actions were explored in terms of combat reward and cultural assimilation. The intent was to demonstrate the ability to generate recognizable macro-level behaviors, such as expansionist and stalemate phases, through simple decision rules embedded within autonomous agents existing in a temporal-spatial environment.

Building upon Axelrod (1984, 1997) and Cusack and Stoll (1990), Lars-Erik Cederman (1997; 2007) developed the Emergent Polarity Model which was later expanded and recast as GeoSim. GeoSim models primitive agents, existing spatially on a square grid, which

[3] Duffy successfully showcased the power of parallel processing by reducing run time by an order of magnitude from over 15 minutes to less than 20 seconds.

[4] In Chapter 2, I describe his changes in more detail and attempt to replicate Duffy's work without the use of parallel processing.

may aggressively conquer neighboring squares by absorbing the newly acquired cell. By endogenously modeling two levels of agents (the state and the province/region), the dynamics between the state (institutionalized government) and the nation (societal norms) can be explored (Cioffi-Revilla & Gotts, 2003). Like EARTH and Sugarscape, GeoSim evaluates IR theories in empirically-free scenarios, largely focusing on the implications of defensive alliances. Cederman (1997) makes the bold claim that if qualitative deductive theories do not hold up in our computational models, there is little reason to believe they would be generally empirically true.

Corr (2002) enhanced Cederman's work with GeoSim Geography, where the ruggedness of terrain was included into the distance calculation. The greater the distance, the less effective the state is in waging war or collecting taxes. He demonstrated how terrain has the ability to protect small states from larger states.

Another significant modeling effort involving EARTH was developed by Min (2002), by integrating Epstein and Axtell's trade model within Sugarscape. Instantiating a modified version of EARTH, Min expanded aspects of the model to include liberal IR theory elements of world politics provided by security and trade, rather than just the former security only model. Min was able to examine the interplay between economic interdependence and war, by comparing system endurance, balance-of-power, and state survival to the security-only version of EARTH. A simplified version of the EARTH model, called Inter-Hex, was also implemented in MASON by Cioffi-Revilla and Balan (2005).

In the mid-to-late 2000s, the research took a decidedly intrastate focus. GeoSim was modified to explore nationalist insurgencies by adding additional terrain and cultural layers albeit in a completely heuristic method (Girardin & Cederman, 2007). A model focusing exclusively on intrastate conflict was developed called REsCape. REsCAPE *incorporates key variables such as ethnicity, polarization, dominance, resource type, and agent behavior* *into a formal computational model which can be used to address the ongoing debates of those studying civil war* (Bhavnani et al., 2008, p. 8). Conflict occurs when group leader agents compete for control of the same territory and outcomes are determined as a function of coercive power, peasant sympathy, and geography. Using a constructivist approach, there have also been notable computational models of political and social identity formation and transformation (Lustick, 2002; Rousseau & Mauritis van der Veen, 2005). However, these focus primarily on domestic, internal social dynamics, not on IR. More recently, Rouleau's NormSim model (2011) did simulate aspects of the IR theory of constructivism successfully emerging behavioral norms in a heterogeneous state agent population.

Perhaps the most ambitious attempt at a more representational IR simulation is the work of Roderik Luteijn (2015) in a NetLogo instantiation of an EARTH-like model exploring virtual scenarios that lead to war between major powers. In this model, states are initiated as multi-province empires, where power is more explicitly represented by population, provinces, GDP, and military capabilities. Alliance-building is no longer ahistorical. In a significant deviation from EARTH, conflict in this model has an explicit magnitude or scope, and is an exogenous factor depending upon the power of the state, asymmetry present in relationships, and trade disputes. The presence of a conflict will prompt a state's rational decision-making to escalate or deescalate the conflict, take action to fight, build alliances, build military capabilities, or submit (surrender). By incorporating additional phenomenology, Luteijn may be the most advanced in the extant class.

Table 1.2: Significance of Relevant Models

Model	Operational Environment				Strategy					
	Military Units	Battles	Terrain	Resources	Production	Trade	War	Alliances	Conflict-Theory	Storytelling
Machiavelli in Machina							✓	✓		
EARTH							✓	✓		
Concurrent EARTH							✓	✓		
Emergent Polarity Model		✓	✓				✓	✓		
EARTH with Trade				✓		✓	✓	✓		
Paths to Great Power War			✓	✓	✓	✓	✓	✓		
Basic RealLand							✓	✓		
Enhanced RealLand	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Table 1.2 illustrates the point of departure across key dimensions and the new features provided by the RealLand simulations. Better computational IR models are needed to explore the conflict and cooperation of states. This history illustrates the immaturity of the field. The criticisms Duffy (1992) levied on Cusack and Stoll in 1990 are still evident today. There is little value to the broader IR community until we move beyond the realist paradigm. However, little progress has been made modeling realism. The EARTH tradition almost exclusively focuses on the armed conflict between states, but with the exception of Luteijn (2015) only represents aggregate power. Verisimilitude in detail is a requirement that abstract cellar automata models cannot overcome. Enhanced RealLand will include the explicit modeling of military units as agents within the simulation. State agents will also behave more like human decision-makers in accordance with the conflict-theory model. The application of the wargaming approach to computational IR yields an additional benefit in providing visual accessibility to the researcher. Human players could easily engage in the same simulation. This storytelling feature provides a pseudo-history not unlike the results of a social simulation.

The RealLand simulations continue the EARTH tradition and advance the state of the art in computational IR. The EARTH tradition is defined as the work initially by Bremer and Mihalka (1977), formalized by Cusack and Stoll (1990), and enhanced by Duffy (1992), Min (2002), and Luteijn (2015). I will continue to reference the EARTH tradition throughout, as a short-hand for this fruitful thrust in computational IR.

The RealLand simulations will build upon the EARTH tradition for several reasons. First, the EARTH tradition has detailed documentation across multiple researchers. While significant issues were present in some of the notation, the fact that Cusack and Stoll (1990) dedicated so much time and energy to experimenting with the model implied a level of maturity that does not exist with the other applications. Second, EARTH's focus on realism theories is quite appropriate for a defense analyst that seeks to inform strategic decision-making for policy-makers. Finally, wargaming was explicitly considered in the construction of the Bremer-Mihalka model (Bremer & Mihalka, 1977). It has many similarities to a forty-four year old wargame called *Conflict* that I have played, helped update, and facilitated in educational settings for over twenty years. The wargame approach to computational IR will leverage the mechanisms with the *Conflict* wargame to obtain more verisimilitude in detail with respect to the operational environment. However, before these mechanisms are described, I review the theoretical foundations of a nation-state in the realist literature and the corresponding approaches to modeling the nation-state within the computational IR literature. The RealLand Framework addresses the question of what should be endogenous, or at least exogenous, within a model of international conflict.[5]

[5]With the objective of simulating conflict between states, my theoretical guides can be grouped in three categories: dominant IR theorists, great military thinkers, and computational social scientists. The first category is the dominant theorists in IR theory, primarily those of the realism school of thought. Realism views states as the key actors in international politics existing in an anarchic system to perpetuate themselves and to dominate, or at least not be dominated by, other states. I looked largely to Hans Morgenthau's *Politics Among Nations*, Mearsheimer's *The Tragedy of Great Power Politics*, and Kenneth Waltz's *Theory of International Politics.* Additionally, I paid close attention to the thoughtful synthesis of realist theories performed by Cusack and Stoll in *Exploring Realpolitik.* I used other scholars as necessary, primarily to argue domestic considerations impact state behavior. The second category is the great military thinkers, primarily Clausewitz in *On War* and Jomini in *The Art of War.* I did make some use of Liddell Hart's *The Sword and the Pen*, which is a collection of the world's greatest military writings prior to the 1970s. The third category is other computational social scientists who interpreted similar concepts in their models. Different researchers draw unique boundaries on their translation from the conceptual to the computational. I consider their modeling choices important to the design of Enhanced RealLand.

1.3 The RealLand Framework: IR Theory and Computational IR Approaches

Arthur Koestler (1967) wrote of the self-assertive and integrative tendencies at the individual, group, and society level. Koestler discussed agents as both parts and wholes, autonomous at one level of observation but existing within an open hierarchical system. This could be a country's strategic decision-maker wrestling with the challenges and demands of the international system while struggling with the personal consequences within the domestic political scene. With the appearance of autonomy, the decision-maker controls the rudder of the state's external actions deciding the best course given the external dynamics and the interests of the state. However, he simultaneously understands the personally consequential ramifications of his actions with respect to maintaining his own power position within the domestic political system.[6]

In his description of agency and structure in the context of IR theory, Wendt (1992) made a convincing ontological case for structuration theory. Structuration theory argues the structure of the international system and the social structures comprising a state together constitute the state and its actions.[7] Wendt recommended a research agenda to understand the causal factors of the existence of a state including an exhaustive list of state actions. The possible state actions are a function of the structural system in which the state exists and the internal organizational structure.

Along these lines, Agnew (1994) argued that there exists a *territorial trap* in IR theory where three assumptions are present. The first assumption is that countries have fixed and secure territories. The second assumption is that there exists a separation between the inner workings of a state and the international system of states. The third assumption is that

[6] Enhanced RealLand does not fully encapsulate all the dynamics within the RealLand Framework and additional components are considered for future enhancements.

[7] Interestingly, even political realist Morgenthau (1973) argues that the state is a socially constructed element flourishing or failing as a function of society.

territorial units are relevant in depicting a society of the state. He argues that states are socially constructed and as such, researchers should not succumb blindly to the methodological nationalism and its essential element of territorial sovereignty.

The inclusion of domestic considerations was a part of the famous inter-nation simulation (Guetzkow et al., 1963). Inter-nation simulation was a computer-assisted social simulation of international politics in the 1960s. However, inter-nation simulation modeled intra-state dynamics in addition to state-level decision-makers and an international system comprised of several other competing states. Initially, human players were chosen to represent a state, a central decision-maker, and one or two external decision-makers. Internal dynamics were computed by the researcher focusing on consumption and national security satisfaction. If the player failed to secure support from his validators, he could be overthrown. Validators were thought of as the power brokers that have influence on domestic elections. After testing concluded that participants did not feel this personal threat, an aspiring decision-maker was poised to replace the current national leader should that individual fail to maintain power. Inter-nation simulation simultaneously situated agents with personally consequential decisions domestically while facing international pressure and conflict as they pursued their national interests. The representative intra-nation dynamics served as a constraining or motivating stimulus on the international stage (Guetzkow, 1963).

Figure 1.1 illustrates the RealLand Framework resting comfortably on the political realism articulated by Morgenthau (1973).

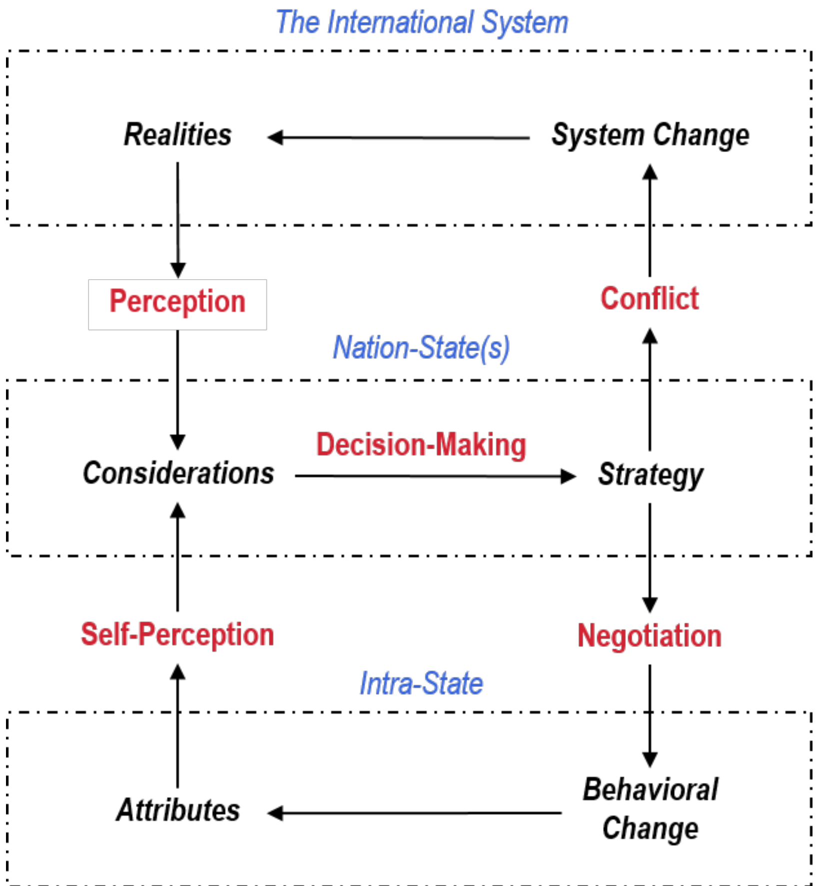

Figure 1.1: The RealLand Framework

Realities and System Change. As shown, the international system has no agency which is consistent with Mearsheimer (2014), Morgenthau (1973), and Waltz (1979). It exists only as a set of realities. These realities characterize the international system at any point of time. The realities are the observable phenomena in the physical world. In 1949, the Chinese communists gained control of mainland China ending the civil war against the nationalists. This presented a new regional (and ultimately global) reality with the emergence of a Chinese communist power that would challenge the West (Kuniholm, 1980). Another reality is the number and capability of carrier battle groups fielded by a country as a force projecting element of national power. As a nation builds another carrier battle group, the international system is updated. Yet another reality may be the rough terrain that exists in eastern Korea that inhibits transit from east-to-west. Simply put, the international system is what exists, some facets of which are relatively stable while others are more dynamic.

External Considerations and Perception. A state's external considerations are the factors bearing on the calculation of national power of other states. Morgenthau (1973) describes a set of elements that together determine national power. He discusses geography, natural resources (including food and raw materials), industrial capacity, military preparedness (technology, leadership, quantity and quality of armed forces), population, national character, national morale, the quality of diplomacy, and the quality of government. He also points to not only estimating the current status but also the importance of forecasting the trends. Morgenthau cautions against assigning too much importance to any particular element.

In discussing the relative power position of states, Waltz (1979) ranks them by population, territory, resources, economic strength, military strength, political stability, and competence. Like Morgenthau, he agrees that their power is a function of all these items.

Mearsheimer (2014) separates a state's potential power as a function of its population and economy as well as the military power of its army, air, and naval forces. More specifically than the rest, he argues that land power is the biggest discriminator between states. He argues that fear over uncertainty of the intentions of other states with offensive military power drives an increase in power. A state should plan against capabilities not intentions. He emphasizes geography (particular large bodies of water), nuclear second strike capability, and the power distribution across the system as important factors. He reiterates, like others, the difficultly in assessing state power.

The EARTH tradition has three main views of power. The first is as an abstract index that allows states to distinguish between the strong and the weak. The power ratio between two states determines the likelihood of victory in a conflict (Cusack & Stoll, 1990). The second view is articulated by Min (2002) as a function of a state's total resources and their metabolism of those resources. Finally, Luteijn (2015) calculates power as the average of the normalized population, territory, economic power, and military power.

Empirically, Singer (1987) created a composite index of national capability (CINC) for the Correlates of War project. It averages the normalized population, urban population, iron and steel production, energy consumption, military expenditure, and military personnel. This has received much attention in the literature as researchers focused efforts on testing and improving the statistical measure (Kadera & Sorokin, 2004).

Something that is knowable is actually known to a matter of degree. State perception of other states is an important element and is why information collection and analysis is often stated as an element of national power. States have greatly enhanced intelligence systems since World War II. The new developments of intelligence-surveillance-reconnaissance satellites, manned aircraft, and unmanned air vehicles (UAVs) provide knowledge of the battlefield not available in the past (Grant, 2003). The influence on war of such systems when held by one country and not by another is extreme. Equally relevant is the state's perception of itself.

A history of the 1962 Sino-Indian War suggests that the Indian leadership had a poor perception of Chinese intentions, an overestimation of their positive relations with both the Soviet Union and the United States, and a self-assessment of greater military capability than warranted. As an aside, the fact that the Chinese major offensive was launched during the Cuban Missile Crisis is often omitted from history lessons. A state is a prisoner of the strategic and tactical information decision-makers utilize in their decision-making process.

The EARTH model includes state misperception as a means to explore the precision in power estimations needed for system endurance (continued survival of more than one state in the system). The consequence is that EARTH presents strategic surprise where one state may find itself mistakenly attacking a more powerful state (Cusack & Stoll, 1990). Similarly, wargaming may include hidden units and/or imperfect intelligence that presents opportunities for operational surprise (Perla, 1990). Sophisticated decoys of valuable military assets are often used to complicate an enemy's targeting. In summary, state perception is the resultant of information collection and analysis on all states including its own.

Decision-Making and Strategy. The inputs into a state's decision-making process are the internal and external considerations. This information is processed in light of a state's goals. The result is a strategy or set of actions to further accomplish its goals within the current environment. This leads us to a discussion of the state's objectives, decision-making procedures, and strategy.

Morgenthau (1973) viewed the primary objective of the state to be the accumulation of power, though he distinguishes between psychological political power and material military force. He argues that all politics can be viewed through a lens of power as individuals, groups, or states seek to keep, increase, or demonstrate power. The demonstration of power may be an attempt to increase national prestige. The space race in many ways was about prestige, but there were military aspects as well.

Mearsheimer (2014) takes a different perspective, arguing that states' primary goal is survival. The structure of the anarchical system, as opposed to human nature, requires states to maximize relative power. Waltz suggests that states imitate the behavior of other states, agreeing with Mearsheimer that security is the highest end. However, additional power may not be the path to greater security. States seek to maintain their relative positions within the system.

In modeling state objectives, Cusack and Stoll (1990) explored a variety of state goals: power seeking, power balancing, power maximization, and collective security. Their differences were in both goals and information processing. Primitive agents were used to test whether rationality was a key component of state survival. The states were not primitive in their search or sensing capability. They still examine every possible first order alternative. The reduction takes place in their internal deliberation. In the EARTH model, rational states forecast the outcome of engaging in conflict against each neighbor and select the one that provides the maximum expected utility. Primitive states will evaluate which neighbor to attack based upon their perceived power ratio. While rational states estimate the consequences of war in advance, primitive states consider only the probability of winning.

In practice, the computational requirements for rationality are rarely met. Cusack and Stoll's rational agents are extremely narrow-minded, failing to take into account the new security situation what a victory or a loss would bring. The cost in terms of development and run-time tend to prohibit agents' forecasting with rational precision and perfect information. The standard is for procedurally rational agents to optimize over the information available thereby functioning under bounded rationality.

In addition to optimizing, there are many other decision-making strategies. Janis and Mann (1977) identify several including satisficing, quasi-satisficing, elimination by aspects, muddling through, and mixed scanning.

- Satisificing is usually a sequential search of options until the first acceptable solution is found.
- Quasi-satisficing is not based upon minimal acceptable solution but a moral justification or simplistic rule that concludes the best decision.
- Elimination by aspects leverages a combination of decision rules as opposed to just

one.

- Muddling through is the art of minor changes while keeping the current policy intact.
- Mixed scanning is a combination of optimization and muddling through where optimization is used for the major decision while minor course corrections are executed via satisficing.

There is no single decision-making procedure that characterizes all decisions.

After sensing and deliberating, the state selects and implements its national strategy. A state's actions are divided into two groups. The first is foreign policy or external actions which include trade, alliances, pre-positioning of military forces, and military operations. The second is domestic policies or internal actions which attempt to increase national power through investment in the elements of national power.

Negotiation and Behavioral Change. Morgenthau (1973) discussed the state's role in pursuing its objectives internationally, while it was pressuring its society to support those pursuits. In turn, the state is transformed by the conflicts, opinion, and needs occurring within its society. To Morgenthau, the state is a product of the society. The essence of domestic politics is no different than the international system. The dynamics of both are built upon the nature of man. Waltz (1979) echoes Morgenthau, discussing nations as being comprised of parts that are drawn together as they interact, but are distanced as they attempt to remain independent. This holds true at the international level, but the ties between states are far weaker than domestic ties.

Additionally, Morgenthau (1973) speaks to the requirement of the state to mobilize the elements of national power to support foreign policies. This could be more resources committed to national defense as opposed to social welfare if the country sees a need for a larger military. It could be encouraging the population to have larger families. In response to serious decline in the birth rate and low life expectancy within Russia, Russian leaders have encouraged larger families. They have gone so far as to declare national days of conception with contests where couples are giving prizes for having babies nine months later. Russian President Valdimir Putin has called the demographic crisis the most acute problem facing the country. This example illustrates how state domestic policies, attempting to change behavior within society, serve their national interests (Weaver, 2007).

Cusack and Stoll (1990) partially addressed this duality. They introduced an empire maintenance cost that, if paid, assured the state would remain integrated with full access to its territorial power. If not, there was a chance that their territories would tear each other apart in civil war. Luteijn (2015) touched on states' ability to mobilize as they can choose to build up military capabilities over and above their normal military spending. In Luteijn's model, most absolute power growth is a function of the growth rate applied to population or GDP, not direct action by the state itself.

Internal Considerations and Self-Perception. Morgenthau (1973) separates the mind of the statesman and the popular mind. Perhaps the most distinguishing feature is the time dimension where a discerning statesman deliberates an enduring solution and the popular mind seeks immediate results to salient issues. Leaders may submit to societal pressure and alter their positions, or they may risk further unrest by maintaining their current position. de Tocqueville (1840) illustrates this point in his discussion of possible American involvement in the French Revolution. At the time, there was a clear majority of Americans that desired war with England in support of the French Revolution. Tocqueville writes that it was only George Washington that served as the stopgap forcing a policy of nonintervention. He was extremely unpopular for this policy at the time. Interestingly, as details of the European conflagration emerged, his policy achieved national support. This tension between taking the wise course of action and the popular course of action is a quintessential element of strategic decision-making.

Shown in 1.2, Cioffi-Revilla's (2009, p. 33) SIMPOL construct provides a model of a system that integrates domestic considerations into the state's calculus. Conceptually, this positions the government on the receiving end of societal pressure based upon its ability to address public issues, which is consistent with the RealLand Framework.

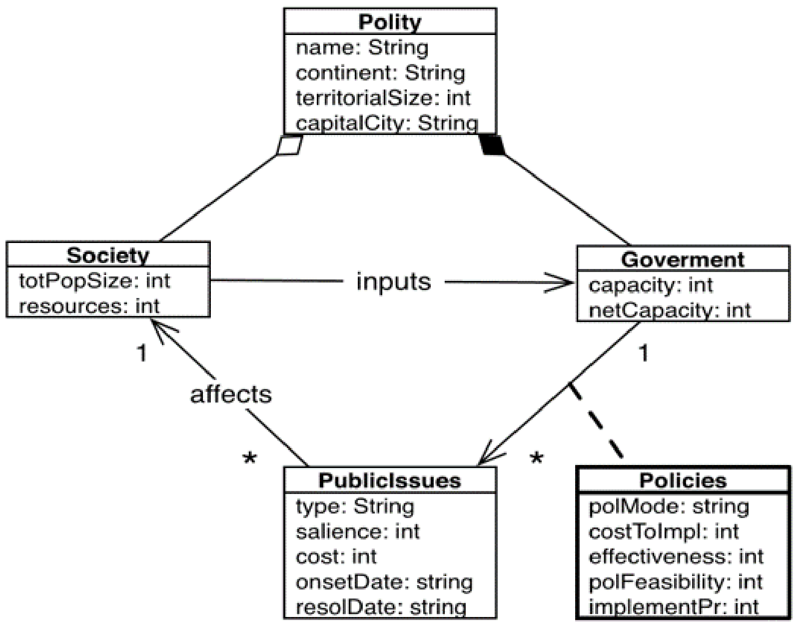

Figure 1.2: Low-Resolution SIMPOL

Attributes. As changes occur within society, the attributes of the state may change. State attributes are the building blocks for the elements of national power which have been previously mentioned. As the elements of national power change, states are pressured to change their internal considerations potentially leading to a new national strategy. States that fail to perceive or address societal issues may suffer a change in regime either peaceably or as a result of civil unrest. The following will address the theoretical justification for the elements of national power.

Strategic Geography. Morgenthau (1973) argues for the lasting importance of geography be it the strategic position of the United States virtually isolated from other great powers by large ocean expanses or the English channel that separates the United Kingdom from the rest of Europe. He argues that the geographic situation of nations is the most durable factor upon which its power is based. The absence of natural boundaries is highlighted as a strategic weakness as easy and nearly unlimited avenues of approach give the invading force a tremendous advantage. Conquered territory may also serve as a liability as the invading nation must secure interior lines in hostile territory as experienced by both Napoleon and Hitler in their ill-fated invasions of Russia. Even contemporary IR theorists who argue against the prevalence of the nation-state as a dominant actor in international politics do not de-emphasize the importance of strategic terrain as an element of national power (Agnew, 1994). Mearsheimer (2014) contends that large bodies of water are obstacles that serve as significant deterrence for land power. There appears to be a significant amount of geographic determinism in the evolution of a state's power.

Military strategists have stressed the importance of geography as well. Speaking on military statistics and geography, Jomini (1862) wrote:

> *By the first of these sciences we understand the most thorough knowledge possible of the elements of power and military resources of the enemy with whom we are called upon to contend; the second consists in the topographical and strategic description of the theater of war, with all the obstacles, natural or artificial, to be encountered, and the examination of the permanent decisive points which may be presented in the whole extent of the frontier or throughout the extent of the country...* (p. 35-36)

Wargaming has a long history of building meaning into grid systems as shown in Figure 1.3. Terrain incorporates relevant natural factors, such as mountains, rivers, and natural resources. Artificial structures, such as airbases and transportation networks, are commonly modeled as well. Figure 1.3 provides an example from a popular modern wargaming series.

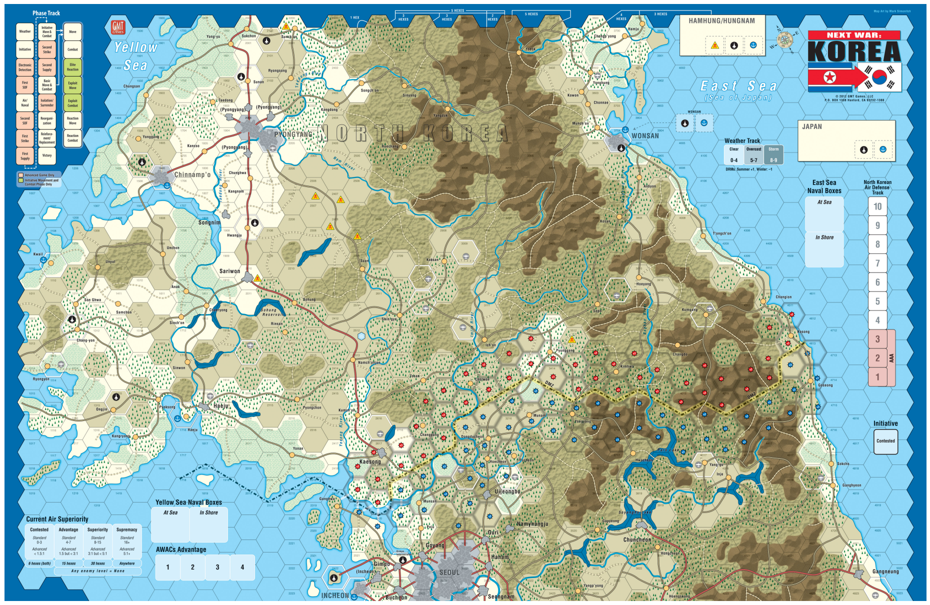

Figure 1.3: Next War: Korea Gameboard

In the early fifties, an American, Charles Swan Roberts II, began the tradition of using the hexagonal grid for military wargaming (Perla, 1990). For wargamers, the advantage of hexagonal grids is that the distance between the center of any hex and the center of any of the six adjacent hexes is equal. This allowed for distance and force presence calculations to be calibrated to the grid, in effect increasing playability of the wargame.[8]

The realism-focused EARTH tradition implemented a bounded system of territorially-based actors, based upon the abundance of realist literature featuring historical analyses of groups of interacting states. The tradition assumed geographic features historically concentrated groups of actors effectively isolating the system for significant periods of times. Realist theories diverged on whether interdependence and isolation leads to more or less conflict. From this interpretation, the EARTH model's abstract spatial representation is not intended to

[8]In practice, this kind of spatial indexing tended to be more convenient for system-style games than using latitude and longitude in a free form geographic system.

be reflective of the global international system. Rather, the more adept example would be ancient Greece or the Italian city-states where there existed a relatively closed system of interconnected states (Cederman, 1997; Cusack & Stoll, 1990). However, the lack of strategic geography or natural obstacles between states within EARTH seems to have negated any progress on this issue. Outside of the EARTH tradition, GeoSim Geography incorporated a ruggedness value that together with Cartesian distance affects the success of waging a war far from an agent's capital (Corr, 2002). Luteijn (2015) in his deviation from the EARTH tradition included more of a common wargaming landscape with resources and water terrain obstacles.

There is one further ontological consideration of geography that is worth exploring. This is the existence of fixed and secure territories. Agnew (1994) argued that there exists a "territorial trap" in IR theory that is not limited to realist thought. One of his points is that territorial control is not a given. A cursory glance at the world illustrates this point. Since the end of the Lebanon civil war, Lebanon still faces ungoverned spaces in the northern Bekaa Valley. Much of Africa has border demarcation conflicts if a border is even discernible at all. The EARTH tradition incorporates an additional cost associated with controlling recently conquered territories. Additionally, maintenance costs are increased with territories in the periphery (proportional to the distance of the state's capital). If the costs are not paid, these states will be more likely to be the source of a rebellion. If the rebellion is successful, they will form a new state actor (Cusack & Stoll, 1990). This treatment may be adequate within a highly abstract system of territorially-based actors, but it fails to address disputed regions that have known intrinsic value. Disputed regions are dominated by presence on the ground. The states are usually in competition for natural resources or strategic positioning. The dispute in the South China Sea between China, Taiwan, Malaysia, Brunei, Vietnam, and the Philippines is a great example where presence equates to control.

Natural Resources. Morgenthau (1973) speaks to natural resources as another element of national power dividing the discussion into agriculture and raw materials. A self-sufficient state gains advantage over a state that must import food. This is true with raw materials and for industrial production as well. Resource acquisition is a means to an end, whether it is feeding the population or building weapons of war.

Japan is a great example of a food security shortfall as an island country with limited arable land and increasing urbanization. Full self-sufficiency in the supply of staple foods is still a significant political issue in Japan as well as a global trade issue. The food shortages in the aftermath of World War II and the sensitivities over the years to American production has created a public issue on increasing the self-sufficiency rate. On the other hand, the Japanese government spends considerable money on farming subsides that could be used elsewhere (Lama, 2017).

Since the early 1900s, oil and gas have become vital strategic resources while iron and coal, stalwarts of the British Empire, have subsided in value. Uranium is another example of a resource with huge strategic implications as a necessary component in nuclear weapons (Morgenthau, 1973). The wealth enjoyed by Saudi Arabia and other states in the Persian Gulf are most obviously the result of vast oil reserves.

The concept of resources as a basis for power did not explicitly enter the EARTH tradition until Min (2002) introduced trade into EARTH. Min integrates the trade module, as instantiated in the Sugarscape model (Epstein & Axtell, 1996), into the EARTH tradition. In so doing, he redefines power as a function of a state's resources and the utilization of those resources (more resources and lower metabolism yield more power). Resources are spatially allocated to cell territories. Min used abstract resources (A and B) identical to the Sugarscape model's sugar and spice.

Luteijn (2015) introduced five generic resources referencing the work of Bearce and Fisher on war and trade. In a closer examination of the Bearce and Fisher (2002) ABM of trade and conflict, they incorporate economic distance as an ontological reality that is often ignored. Economic distance appears to be a function of actual distances and the maturity of the trading partnerships. They introduce a fixed cost associated with trading based upon the economic distance of the trading partners. The more mature the trading partnership, the less economic distance between the states, the lower the cost. This allows for a mechanism for trading partnerships beyond simple adjacency.

Industrial Capacity. Another important aspect of the environment is industrial capacity, in this case the ability to harness resources to produce military forces and related advances in technology. Mearsheimer (2014) defines a *mobilizable wealth* as the economic resources a state can contribute to military power. He also points out the cutting edge technological sophistication needed for modern warfare. He suggests Gross National Product (GNP) as a good indicator of latent power. Morgenthau acknowledges the value of the industrial military complex that builds the modern warfare capabilities. Wealth may be reapportioned from domestic welfare programs (or vice versa) if necessary to maintain peace at home or achieve objectives abroad.

Within the Earth tradition, a region's strategic importance is represented only by its endowment of power. Only Luteijn (2015) assigns income, people, and resources to a cell. Industrial capacity is often physically located. The shipyard in Newport News is a good example of a strategic asset and target. There are few other places in the world where aircraft carriers can be built.

Population. Morgenthau (1973) points out that great powers necessarily are among the most populated countries, but population size is not a sufficient condition to be great. Uncontrolled population growth can threaten states when the food supply cannot keep pace. Population trends are important considerations as the previous example of Russian birthrates illustrated. Another aspect of population is that urban areas tend to have important defensive military strategic value.

Luteijn (2015) included a simple representation of population existing within cells with a growth rate parameter leaving it to future researchers for expansion.

Military Technology. Technology has long been a discrete differentiator between military forces and remains so today. Mounted knights, armor piercing crossbows, machine guns, stealth aircraft, and nuclear submarines are all examples of technological advancement. History is replete with such examples and none greater than the advent of nuclear weapons. North Korean dogged defiance of the international community to pursue nuclear and missile technology is no surprise. The nuclear threat remains the best deterrent against overt hostile regime change.

In other cases, advanced technology provides alternatives to more developed states when aggressive action is untenable. Throughout the 1990s, Hezbollah in Lebanon had been launching rockets into northern Israeli cities. While occasionally targeting arms smuggling in Lebanon, Israel finally retaliated unsuccessfully with its invasion of Hezbollah strongholds in southern Lebanon during the Second Lebanon War. Thousands of rockets were shot into Israel during the war. Faced with the inability to conventionally attack Hezbollah's irregular threat, Israel developed Iron Dome, which shoots down short range missile attacks with amazing success. Hezbollah is no doubt seeking capabilities to render Iron Dome obsolete or too expensive to maintain. Military technology takes the form of action, reaction, and counter-action as states seek to maintain or gain power advantages.

Only Luteijn (2015) considered technology explicitly, estimating technological advancement as a function of gross domestic product per capita divided by the average GDP per capita of states within the system.

Military Leadership. Morgenthau (1973) calls out leadership as having a critical influence on national power, citing the examples of Frederick the Great and Napoleon. Clausewitz (1832) provides a detailed essay on the character of military genius. Clausewitz concludes that inquisitive, comprehensive, and cool minds come the closest to military genius when combined with the requisite training and experience. The similarities with the conflict-theory model's vigilant pattern of decision-maker, described in the next section, are striking. Thus, a military genius is one that executes a vigilant pattern of information processing, among other attributes.

Quantity and Quality of Armed Forces. The quantity and quality of the military are obvious elements of national power. Strength and capability are functions of the total force (how large) and force shaping (what types). The question of standing armies poses difficult questions. How much national treasure should a nation spend on its defense during peacetime? Is a small, modernized combined arms force sufficient or are large numbers of ground forces needed? Any national defense strategy and available military forces are a state's current position with respect to these questions in the light of domestic and international considerations.

Mearsheimer (2014) and his theory of offensive realism provide additional clarity. Similar to Morgenthau, Mearsheimer argues that a state's power is either latent or military. Latent power is the capability and capacity to build military forces that stem from wealth, technology, and population. Military might is the only source of actual power. Consequently, the size and composition of forces are the most important variables. In strategic terms, the military can be separated into ground, naval, air, and space forces. Ground forces are necessary for conquering and holding territory. Naval and air power have supporting roles during ground operations. However, they dominate in securing the ability to project power and keep others from projecting power. For the strategic comparison of military forces, he examines the number and quality of soldiers, weapons capabilities, and the organization of each branch. As necessary, Mearsheimer includes the strategic value of military capabilities such as ISR, command and control, and ground-based air defenses. ISR and command control have a heavy reliance on space assets which have become increasingly militarized.

Mearsheimer also argues that states will not build additional military forces if they perceive a diminishing margin of return. States will often seek to trim defense spending to support domestic priorities in peacetime. Some states may believe that defense spending may undermine the economic situation leading to less wealth. Alliances have an impact as well as states with rich friends historically spend less. Some states are kept weak intentionally by other states. In Europe after World War II, Secretary General Hastings Lionel Ismay articulated the objective of the North Atlantic Treat Organization (NATO) *to keep the Russians out, the Americans in, and the Germans down.* For whatever the reason, rich states may have a small military.

Much of the EARTH tradition is silent on representing military forces in detail and only addresses the resulting power. However, Luteijn (2015) incorporates military strength as function of technology and military force. For Luteijn, force is accumulated over time through defense spending. Luteijn was guided by the arms race literature with the tradition of viewing military spending as a percentage of Gross Domestic Product (GDP). The wealthier the country, the more potential for a stronger, more technically sophisticated military. Increases in military spending tend to lead towards greater military power. Increase in military power is constrained by the burden of maintaining existing forces.

Outside of EARTH tradition, multi-agent models of conflict have been generated. Ilachinski (2004), in his EINSTein model, simulates small unit tactics by representing each individual solider. More traditional detailed simulations of military warfare do exist within defense analytic communities across the world. The Synthetic Theater Operations Research Model (STORM) is the primary military campaign analysis tool in the Department of Defense.

STORM is used to provide analysis on comparative force structures, concepts for employment, and capabilities. STORM provides a theater-level simulation of an incredibly detailed specific military campaign. A complex model with over a million lines of code, it is a complicated endeavor to operate and understand (Bickel, 2014).

National Character. Morgenthau (1973) discusses the effect of national character as it contributes to the ability to convert national resources to the military. Some societies have higher thresholds on the build-up and use of military force, meaning some societies will tolerate larger military industrial complex and a larger standing military. Nations with higher thresholds will find it easier to start a preventive war. Others with lower thresholds may not have enough force to service all their policies. Similar to the way parents imprint on a child, the culture and structure of a society molds its citizens. These societal qualities have a structural impact on the aggressiveness of foreign policy. Morgenthau's argument behind a national identity suggests an even more complicated theoretical framework than what I'm proposing here. Morgenthau accepted its existence without discussing the factors by which national character is formed or transformed.

National Morale. Morgenthau (1973) defines national morale as the degree to which society supports the policies of the state. It weighs on the effectiveness of all activities of the state. Morale is seen as a military force multiplier. The Battle of Thermopylae where three hundred Spartans slowed the Persian advance into Greece is a popularized example where morale appears to have played a factor. In this case, morale could be considered the sense of national allegiance that tends to fight when the fight or flight quandary is triggered.

Disenfranchised groups within a state may have significantly less morale. Additionally, deep divisions within a society often stymie support of a foreign policy. Conquered people are likely to resist the conqueror with much of the allegiance they retain to their former authority.

National morale may have more to do with effective leadership than anything else. Morgenthau (1973) asserts that the quality of the government, its effectiveness, is the single greatest predictor of the capability to marshal national power.

Quality of Diplomacy and Government. Morgenthau views diplomacy and governance as the twin architects of national strategy. In the RealLand framework, the quality of diplomacy and government is embodied in the decision-making process of the state. Morgenthau (1973) stated the following:

> *Diplomacy, one might say, is the brains of national power, as national morale is its soul. If its vision is blurred, its judgment defective, and its determination feeble, all the advantages of geographical location, self-sufficiency in food, raw materials, industrial production, military preparedness, and size and quality of population will in the long run avail a nation little...* (p. 140)

If diplomacy is facing outward, governance is looking inwards. Morgenthau (1973) considers governance as having the responsibility to balance the scales between domestic realities and foreign policy initiatives. It must align the national power to the national priorities ensuring the right mix of resources. It marshals popular opinion while attempting to resist its pressures. How this is done is viewed by other nations around the world and can be a source of prestige or ridicule.

Decision-making and strategy were previously discussed. The point to remember is that the quality of the state's strategic decision-making is itself an element of national power.

Summary. As Waltz (1979) writes, *Just as peacemakers may fail to make peace, so troublemakers may fail to make trouble. From attributes one cannot predict outcomes if outcomes depend on the situations of the actors as well as on their attributes* (p. 61). The RealLand Framework sets the conditions for justifying modeling decisions including the wargame mechanisms pulled from the *Conflict* wargame.

1.4 A Wargaming Approach: Mechanisms for Enhanced RealLand

Modeling, simulation, and analysis of sociopolitical systems, particularly warfare, has existed since long before the emergence of modern academic scholarship. In the 6th century BC, Sun-tzu, a Chinese general and military theorist, created a game called Wei Hai. In Wei Hai, players moved their colored stone armies in an attempt to outflank and encircle opponents. Sun-tzu attempted to educate his warriors on tactical insights before the battle. In the 1800s, the Prussians formalized *Kriegsspiel*, which explicitly simulated warfare through interactions of humans, procedural rules, and an artificial game space (Perla, 1990). For the study of war, wargaming refines the operational environment and forces players to grapple with the complexity of the decision in a competitive environment.

Since the late 1900s, wargaming has blossomed into a professional discipline and commercial industry at all levels of analysis and across domains, such as defense, organizational development, disasters, and business (Herman & Frost, 2008). Wargaming is lauded for its ability to synthetically generate a situation where human players are often forced to make agonizing decisions in the face of some impending challenge or opportunity. Unlike cold calculations within an experimental laboratory, wargame designers relish the chance to create immersive gaming experiences that reach players at the psychological level. Excitement at a victory, apprehension at the eve of an engagement, post-decisional regret after overlooking an important data element, and despair after a significant failure, are all within the emotional landscape of a well-constructed wargame. Continued development of wargaming techniques has been incorporated into the study of IR, because military objectives are linked to diplomatic and political goals (Ellis & Greene, 1960). Without even playing the the wargame, wargaming mechanisms provide a visual representation for the decision-maker to see the operational environment and decide a course of action. The representation of terrain, military units, combat adjudication, and production were used in the development of Enhanced RealLand. This additional resolution provides verisimilitude in detail that is otherwise absent from computational IR models.

Wargaming is useful for examining military problems by generating a representation of an operational environment where players compete to accomplish their objectives. This section provides a detailed orientation to a particular wargame, called *Conflict*, that inspired some of the features of RealLand.

The original form of *Conflict* was developed in 1973 by then-Captain Robert Selke to teach national defense policy to Air Force ROTC cadets. His hobby wargame is a structured wargame representing sovereign states competing for national power (Selke, 2004).[9]

Conflict operates at a global scale, but it also provides regional insights. As a nation-state, the participant is forced to plan political and military goals strategically, but in pursuing individual objectives the participant confronts operational problems (Simpkin, 1985, p. 23). Different theaters of conflict all compete for limited resources of the country. These theaters are contained in scope by the goals of the nation-state and the power the nation-state possesses to implement its policy. Its original form, developed in 1973, was a post-WWII era multi-sided wargame. Over the years, it has upgraded to its current form, which includes advanced technologies such as precision-guided munitions (Selke & Selke, 2008).

[9] Colonel Selke (Ret.) is my father.

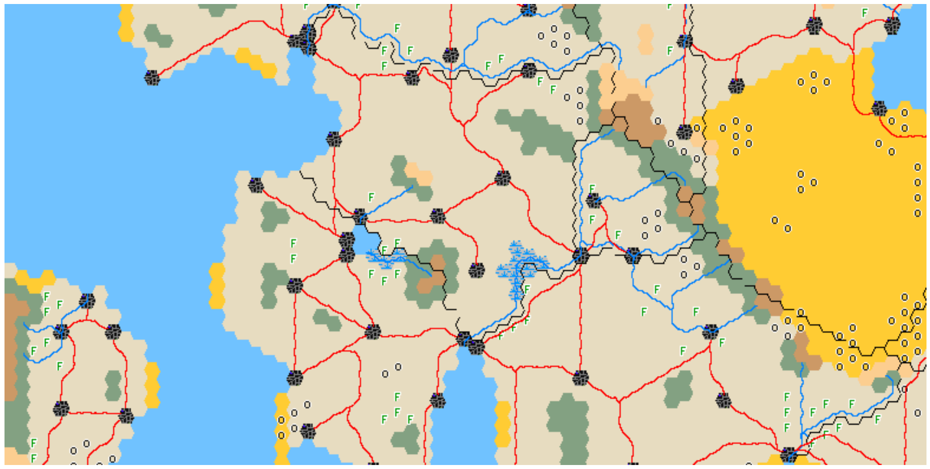

Figure 1.4: Southwest Quadrant of *Conflict* generated by *Aide de Camp 2* software

The original *Conflict* was essentially a more advanced version of the Avalon Hill board game called Blitzkrieg and the enhancement, called Blitzkrieg Module, produced by Simulations Publications Incorporated (SPI). Blitzkrieg is a structured two-player operational wargame. SPI added more unit variety and upgraded the rules. It consisted of each player controlling a major country with five neutral minor counties. Blitzkrieg was played with World War II forces on hex graph paper with colored terrain. *Conflict* made some significant deviations from the Blitzkrieg design. The first obvious difference was a much larger hex board to provide more game space. Forces and weapon effectiveness ratios were updated to the Cold War. Cold War style naval forces were also introduced to the game. The most important deviation from the Blitzkrieg game was the number of players. Selke was teaching eighteen people in his defense policy class; thus, he created a fictional map board with eighteen countries (eighteen players) in his game. This step transformed a complicated chess game of two opponents into a world of political intrigue as eighteen players sought conflicting goals. In addition, a referee was added to the structure to ensure fair play among the many players. Selke (2004) states:

> *Countries were asymmetrical with varying numbers of cities, geography, natural resources, levels of technology, industrial capability, and types and numbers of*

forces. Countries ranged from large with advanced force types to small with infantry-only armies. Shortfalls and surpluses in natural resources varied from country to country. (p. 8)

Selke was attempting to create a game that would educate the players on national defense policy. In doing so he introduced many new elements. First, each player controlled a country, acting as the unitary actor of that nation in either a rational or irrational manner. Second, natural resources were added to the game. Third, international conflict and elements of power were explored as nations flexed their muscles in attempts to obtain their objectives. Each student was also assigned three weighted objectives to encourage cooperation and instill conflict in the simulation. Aside from the three objectives, students were given complete diplomatic and trade freedom. The winner was not the last country standing, but determined by a formula normalizing the elements of national power to measure countries growth (if any) from the beginning of a game. Thus, even the weakest country could win if it played well. According to Selke (2004), the students were receptive to the game:

> *My game objectives were realized. Students quickly grasped the capabilities and limitations of the different force types. They understood the importance of interior lines and unimpeded lines of supply. Weather became a meaningful factor. They sought favorable trade agreements and mutual assistance treaties. History and Defense Policy became a little more real and understandable through a board game.* (p. 9)

My personal involvement in the design and play of *Conflict* dates back over twenty years with hundreds of hours playing, designing, and testing elements of the wargame. A single turn takes approximately one hour to play. The free play decision-making of the wargame made each iteration different and exciting. The structured employment of military forces provided a verisimilitude in detail that made the results more generalizable to current events. My last experience facilitating a *Conflict* wargame was in fall of 2017 with a group of eighteen defense analysts who gathered to play for a few hours.

Conflict, like most military wargames, provided a detailed representation of operational environment to include military forces. These mechanisms were adapted for Enhanced RealLand:

1. As a board wargame, *Conflict's* hex grid map system includes different types of terrain, such as forests and mountains, and geographic features, such as roads and rivers. Natural resources are also provided in the form of wheat and oil. Enhanced RealLand was constructed using these features as a guide limiting only the types of terrain.

2. *Conflict* includes a sophisticated production system where periodically players are able to purchase additional military units, increase production capacity, or invest in natural resources. Enhanced RealLand implements this design.

3. *Conflict*'s purpose is to examine how nation-states attempt to increase their national power. Consequently, *Conflict* consists of generic unit types. The differences between an American and German Tank in WWII are not relevant. This is an example of realism in *process*, not data. Precise data is often a distraction in the education and research of foundational principles. Enhanced RealLand implements generic unit types where differences in combat strength is a function only of the type of unit as opposed to the state.

4. *Conflict* consists of many different unit types. The aircraft in the game include air-to-air fighters, ground support fighters, advanced fighters, strategic bombers, medium-range bombers, and many more different types. Some ground units in the game are armor, infantry, rangers, guerrillas, mechanized infantry, paratroopers, and marines. Naval units, nuclear weapons, helicopters, and supply units are also game units. Each generic unit has its distinguishing characteristics documented in the manual. As a proof of concept, Enhanced RealLand includes several types of grounds and air units.

5. In *Conflict*, the relationship between unit types and terrain is taken into account for

realism in process. For example, armor units suffer penalties for moving in forest terrain while rangers do not. Regular infantry move at a slower pace and are unable to concentrate to the level of armor or mechanized infantry units. Enhanced RealLand currently includes terrain's impact on combat adjudication. Movement is only constrained by unit type.

6. In *Conflict*, combat adjudication is handled by combat results tables. Enhanced RealLand incorporated several tables to adjudicate ground combat, air combat, strategic bombing.

1.5 A Conflict-Theory Model for Enhanced RealLand Agents

A wargaming approach to computational IR considers how strategic decision-makers make decisions. In their landmark book *Decision Making*, Janis and Mann (1977) proposed seven criteria for ideal decision-making.

- Explore a broad range of alternative courses of action (COA).
- Survey objectives and then explore their fulfillment in each alternative COA.
- Weigh costs and risks of negative or positive outcomes for each alternative COA.
- Collect relevant information to support evaluation.
- Incorporate new information without bias.
- Reevaluate all COA options before making a decision.
- Make contingency plans.

The Janis-Mann ideal criteria imply that the more decision-makers stray from these procedural criteria for important decisions, the more problems they will encounter due to the defects in their process. Janis and Mann (1977) identified defective patterns of decision-making and explored causes. Two major decision-making obstacles dominate their analysis.

The first is an ineffective or limited search for alternative COA. The second is the tendency to bias the understanding of data. They point to the Gambler's fallacy as an example: A gambler, down on his luck, continues to gamble waiting for his luck to return as if fate were self-correcting, not determined by completely independent events.

Janis and Mann (1977) provide a descriptive model, shown in Figure 1.5, of how human beings make decisions under psychological stress based upon experimental, field, clinical, and historical investigations—i.e., behavioral decision science under conditions of bounded rationality (Simon, 1996; Cioffi-Revilla, 2014), not idealized rational choice theory. They define stress as an undesirable emotional condition caused by threatening environment stimuli from emerging and concurrent issues. They assume that decisional conflict, a function of the perceived gain or loss associated with the decision, inevitably produces stress. Stress is further compounded if the decision-makers are forced to consider an alternative contrary to their desired or committed course of action.

Issues with little or no decisional conflict warrant little to no additional information processing. If there is no risk in doing nothing, the tendency is to stay with the current course of action. A ship captain observing a storm on the horizon, but believing that it will pass north, will stay the course. Alternatively, if the captain believes they are riding into the teeth of the storm, he will likely change course without any serious hesitation.

In the case of significant decisional conflict where there is no perceived hope for a satisfactory or better solution, the decision-maker may fall into a defensive avoidance pattern. In this case, the ship captain commands the crew to batten down the hatches and sails to his doom. Defensive avoidance is a form of self-deception where delay or wishful thinking is used as a substitute for facing reality. Ignoring evidence to the contrary, people have an uncanny ability to believe what they want or persist towards an unattainable goal because of a sense of commitment (Janis & Mann, 1977, p. 92).

Similarly, if there is no perceived time to find or deliberate a superior solution, the decision-maker will be in a state of panic or hypervigilance. Suddenly threatened by a storm far more powerful than imagined, the ship captain races to prepare the ship for a battering in the high wind and surf. With the crew unable to lower the sails and fearing that the mainmast will be torn asunder, he gives the order to cut down the mainmast. The ship survives but is blown way off course, and without the mainmast, the ship is unable to find safe harbor before water and food are gone. If the captain had believed time was available to prepare the ship, he would have considered the impact of cutting the mainmast. Realizing the consequences of that decision, the captain would have challenged the crew to make all effort at lowering the sails.

As an illustrative policy example, consider the news of significant North Korean progress on an intercontinental ballistic missile (ICBM) facing the United States Administration. The threat briefing to POTUS (President of the United States) states that the charitable policies of the past have failed and, if nothing is done, North Korea will have an operational nuclear ICBM capable of striking the west coast of the United States within some dire period of time. It is likely that this would catapult the conversation into risks associated with military strikes on North Korean facilities, the likelihood of South Korean and Japanese concurrence, the range of possible North Korean responses, and potential escalation by Russia and China. Given the prolonged failure to effect a termination of the North Korean nuclear program and the prevalent view of the untenability of strikes against North Korea, some administrative officials would attempt to identify an exit strategy from the crisis. This might raise the prospect of discounting the possibility that North Koreans would actually use the capability; however, someone would undoubtedly raise the concern of a nuclear deterrent to US intervention in the event of a North Korea conventional attack on South Korea, and the proliferation of this technology to the Iranians. Eventually, a technologist in the room would raise the promise of anti-ballistic missile defense, stressing

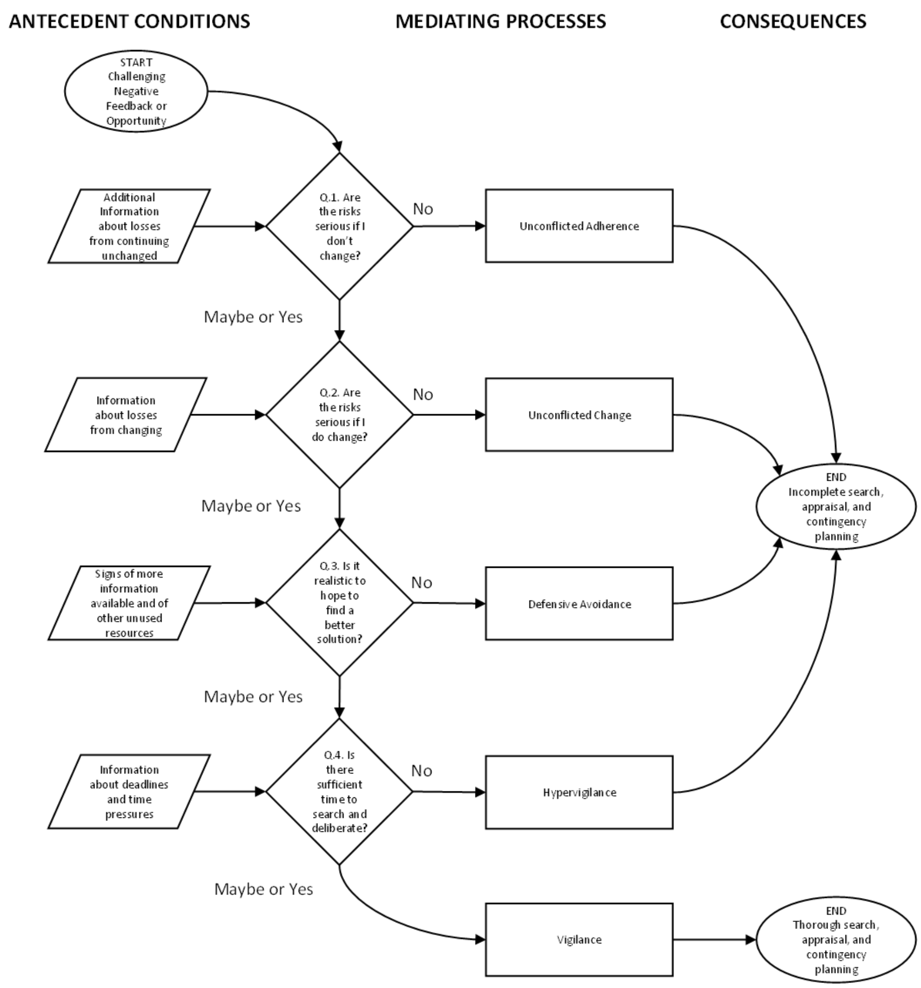

Figure 1.5: Janis and Mann's (1977, p. 70) conflict-theory model

the need for more money in development, testing, and fielding new advanced capabilities. The President would end the meeting saying that we need to continue the current policy of economic and diplomatic pressure and continue investing in the ability to prevent any North Korean missiles from hitting us or our allies. Everyone would nod in concurrence that technology would be the panacea and continue with their day. Of course, developing, testing, producing, and fielding advanced capabilities must survive the budget and appropriation process and is a distant solution for a future problem, not a current crisis.

While a superficial example, it is sufficient for scoring against the idealized procedural criteria identified by Janis and Mann for quality decision-making. The President would score reasonably well for ensuring the meeting unearthed and debated potential courses of actions, but not so well on determining the likely negative and positive outcomes of each alternative. In this example, he also fails to address detailed contingency planning to support decisions that he might have to make in the future. The meeting ends when a course of action is selected that requires little change and consequently, little risk of change. This type of temporizing arguably is what led to a nuclear North Korea. Perhaps a rigorous analysis of possible actions and outcomes in the past could have developed a policy or intervention that would have precluded the current state of affairs. However, it is certainly in a sovereign North Korea's best interest to have that nuclear capability as a deterrent.

The conflict-theory model draws an immediate connection to Carl von Clausewitz (1832) when he stated that *theory must also take into account the human element; it must accord a place to courage, to boldness, even to rashness* (p. 117). Like Clausewitz, I assume that passionate, emotional human beings are the primary authors of their fate. As such, there is value in working conflicts or challenges in advance to test and explore courses of action in a stressful environment. Traditionally, this has been accomplished through wargaming and IR social simulation, where human players are situated within a synthetic environment and forced to make decisions. By adopting a wargaming approach, Enhanced RealLand incorporates this concept into computer simulation.

1.6 Overview of Next Chapters

This chapter introduced the motivation for the Enhanced RealLand simulations and provided an in-depth look at CSS models of international conflict, particularly the EARTH tradition. Additionally, this chapter introduced the *Conflict* wargame discussing features that were incorporated into Enhanced RealLand, and explained in some detail the conflict-theory model that serves as the basis for the decision logic within Enhanced RealLand's state agents.

Chapter 2, *Methodology*, will present Basic and Enhanced RealLand in accordance with the motivation, design, implementation, verification, validation, and analysis (MDIVVA) framework. MDIVVA is a CSS methodological protocol for quality control and for establishing procedural integrity (Cioffi-Revilla, 2014).

Chapter 3, *Results*, will provide the insights gained through the construction and analysis of the RealLand simulations. A single run of the model will be described in detail to illustrate the verisimilitude. Model behavior will be compared against certain realist perspectives on power distribution, rational decision-making, and war costs. Finally, additional results will be generated leveraging Basic RealLand agents within the operational environment defined in Enhanced RealLand.

Chapter 4, *Discussion*, will evaluate the two models in accordance with standard modeling assessment criteria. The chapter highlights the key original contributions of this effort and the broader implications. Additionally, it discusses future directions for the development of Interactive RealLand, approaches for further empirical validation, and potential applications to historical, contemporary, and future interstate conflict.

Finally, Chapter 5, *Conclusion*, summarizes and concludes the effort.

Chapter 2: Methodology

> It is commonly regretted by busy, responsible policy-makers that action seems to be the enemy of thought.
>
> *Perspectives on the Use of Experimental Techniques*
> Richard Snyder

Each RealLand simulation was developed in accordance with the Motivation, Design, Implementation, Verification, Validation, and Analysis (MDIVVA) framework, a methodological protocol for quality control and for establishing procedural integrity (Cioffi-Revilla, 2014). Although the CSS terminology differs slightly from the professional research standards of traditional social science, there are many similarities:

- Verification and validation within CSS are synonymous with internal and external validity as described by traditional social science. Verification is the determination of whether the simulation performs as intended and validation is essentially the determination of the degree to which the results approximate the real world (Cioffi-Revilla, 2014). Complete validation is rarely claimed in computational IR where the emphasis is on empirically free or fictitious scenarios. At best, there is the emergence of trends and behaviors that are seen in empirical research. In model assessment, another name for verification and validation could be *truth*, as described in Cioffi-Revilla (2014, p. 238-243).

- Reliability, or measurement accuracy, within a verified and validated simulation tends to be less important than empirical sampling techniques. Measuring error is not an issue within simulation; however, understanding the simulation's output is a key result of the model analysis step where virtual experimentation takes place. However, good practice in analyzing a stochastic simulation is expected.

- Within CSS, replicability has the same meaning as traditional social science. Can other researchers duplicate the results? This is usually addressed in the listing of parameter and sometime random seed values for simulated runs. Sometimes modelers will save the experimental run parameters within the model itself to expedite the process. Regardless of the documentation, the inability to control the random seed or replicate specific experiments suggests a significant model design flaw.

- Generalizability has to do with whether the experimental findings have broader applicability. While related to verification and validation, generalizability in CSS has to do with the translation of insights from the simulated world into the real world. While abstract and game-theoretic, Axelrod (1984) had an impact on the world through experiments with an iterative prisoner's dilemma, and specifically the tit-for-tat strategy. In model assessment, another name for generalizability could be *justice*, as described in Cioffi-Revilla (2014, p. 238-243).

- Parsimony is a key measure in CSS as well as traditional social science. The model should be no more complex than is required. In CSS, parsimony is often tested through layering of additional complexity. Additional resolution is not required if the targeted behavior is achieved. In model assessment, parsimony is often linked with *beauty*, as described in Cioffi-Revilla (2014, p. 238-243).

This chapter presents Basic RealLand and Enhanced RealLand. Basic RealLand is a replication of the work of past researchers with some additional extensions. Basic RealLand is used to perform the same experiments and regression analyses as previous scholars. The results are then compared and analyzed against the previous work. In the next chapter, experimental runs are described where the operational environment afforded in Enhanced RealLand is combined with the agent logic in Basic RealLand. This is intended to inform the third research question described in Chapter 1. Enhanced RealLand is a proof of principle of a wargaming approach to computational IR developed in response to the research questions. As a new approach, the analysis is primarily concerned with the impact of noise, parameter variation, and varying initial conditions on the structure of the international system. The verified model itself, with its additional resolution and instantiation of the conflict-theory model for agent decision-making, is the main result and its output is described in Chapter 3 to inform the research questions. An assessment of both Basic and Enhanced RealLand will be discussed in the Chapter 4 documenting the strengths and weaknesses of the models in accordance with professional standards.

Before beginning the discussion of each model, there are some core concepts present in both that are worth highlighting:

- States are composed of one or more grid cells that generate value to the state. Basic RealLand gives each cell a power allocation that contributes to the overall power of the state. Enhanced RealLand provides a similar distribution except power is disaggregated into discrete components. A state could be rich in natural resources but low in population.

- Additionally, states may directly interact with other states. Basic RealLand constrains the states largely to contiguous interactions of war. Enhanced RealLand takes a significant step forward by simulating military forces, which opens the aperture for noncontiguous interactions.

- In each simulation is the concept of an iteration, tick, turn, or time step. A turn is comprised of one or more phases where states act in a sequential manner. This is an approximation of simultaneity that would occur during that increment of time in the real world.

- The last important conceptual similarity is that during each turn, agents are compelled to sense the environment, interpret the situation, and decide to take action. A turn in Basic RealLand is largely meaningless, representing the ability for a single agent to take action. Enhanced RealLand views a turn as approximately one to two weeks.

2.1 Basic RealLand

2.1.1 Motivation

Basic RealLand is built upon the EARTH modeling tradition (Cusack & Stoll, 1990; Duffy, 1992) which situates nation-states competing within a spatial network topology. The network topology is grid system where states directly engage only with adjacent states and may build alliances only with countries that are within one degree of separation (i.e., states adjacent to opposing states). Figure 2.1 shows the square and hex grid world at initialization. The flags are used to represent each individual state with a corresponding cell color of a slightly different shade. The standard EARTH world is the 98 state-system within a hexagonal grid established by Bremer and Mihalka (1977), with slight deviation to a 128 square-based state-system to support the parallel computing environment described in Duffy (1992).

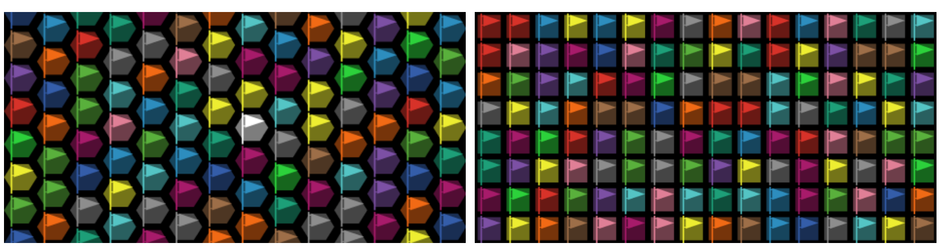

Figure 2.1: Basic RealLand: Replicated EARTH Environments

In realizing the tradition of the early models, Basic RealLand provides insights to two central questions:

1. How does the structure of the international system affect system endurance?

2. How does increasing the resolution of the model affect the findings from Cusack and Stoll (1990) to Duffy (1992)?

The next section will discuss the structure and dynamics of the model. As a replication effort, the design work described is closely associated with the EARTH tradition and a majority is not of my own creation. However, the description presented here as Basic RealLand is a distinct implementation combining elements of work from several researchers and my own extensions.

2.1.2 Design

Structure

In Basic RealLand, the states comprising the international system are computer agents. Initialized with a single territory, states seek to grow and maintain multi-cell empires. State power is aggregated into a single state variable as the sum of the power of its controlled cells. Given an initial allocation of power, states gain additional power through iterative growth or the spoils of victory. States can also lose power through war costs, empire maintenance costs, and losses associated with wars. The states are given 1,000 iterations to rise as empires or become vassals of other states. Conquered territories may choose to rebel if they fall under delinquent masters. States have two key characteristics that are worth extra attention: perception and decision-making.

State Perception States' perception of themselves and others can be subject to a varying degree of error. Basic RealLand introduces a normally-distributed state-specific, object-specific error term ($e_{i,j}$) with a mean of zero and a user-defined standard deviation. This implementation allows maximum flexibility by providing an array of all states with the associated error term, including themselves, that may be varied or constant throughout the simulation. States can have a unique error term for each other state or consistently misperceive all other states using the same error term. Additionally, a state's self-perception can be subject to error. The state's error rates can be recalculated each iteration if desired.

In other words, the error rates can be drawn from the distribution at initialization, or each turn.

State Decision-Making Within Basic RealLand, each state is a unitary actor with decision-making logic governing target selection for acquisition (war), escalation, and alliances. Potential targets are contiguous states. Four types of logic are instantiated: primitive power seekers, power balancers, collective security actors, and rational actors. Primitive power seekers and power balancers will initiate a dispute with the contiguous neighbor that they perceive as the weakest inferior opponent.[1] Primitive power seekers and power balancers will continue to escalate the conflict while they perceive a superior position. Collective security actors will never initialize a conflict. Rational states assess war with their neighbors differently by calculating their perceived expected utility against each and selecting the state as a target that maximizes its positive expected utility. This limited forecasting calculates first-order effects only, ignoring potential counter alliance formations and the consequences of the resulting security situation. Collective security and power balancing actors will always join defensive alliances but never join the aggressor's coalition. Primitive power seekers will only join what they perceive to be winning coalitions. Rational states will join if there is positive expected utility once again simulating the conflict from their perspective.

Dynamics

Basic RealLand has six distinct phases within the course of a simulation iteration. These phases are civil war, initiation, escalation, war, and power adjustment. All multi-cell states are subject to some chance of disintegration during the civil war phase. If a civil war does occur, the phase adjudicates the outcome including the creation of new states. The initiation phase determines the potential options for a state leading to a decision of war or to do

[1]Here, Basic RealLand includes an extension to the original EARTH model for non-rationale initiators by including a distance from core weighting. In the case of potential target states with near similar power levels, the state will target the one closer to its core territory. This change was included when observing that states tentacle-like growth creates increasing susceptibility to division.

nothing. The escalation phase provides for target and attacker coalition development. The war phase adjudicates any wars to include war costs, reparations, and territory reallocation. Finally, the power adjustment phase resets for the next iteration, handles any power adjustments, and allocates empire maintenance costs. The simulation ends when the iteration limit has been reached. The following subsections will describe each phase in greater detail.

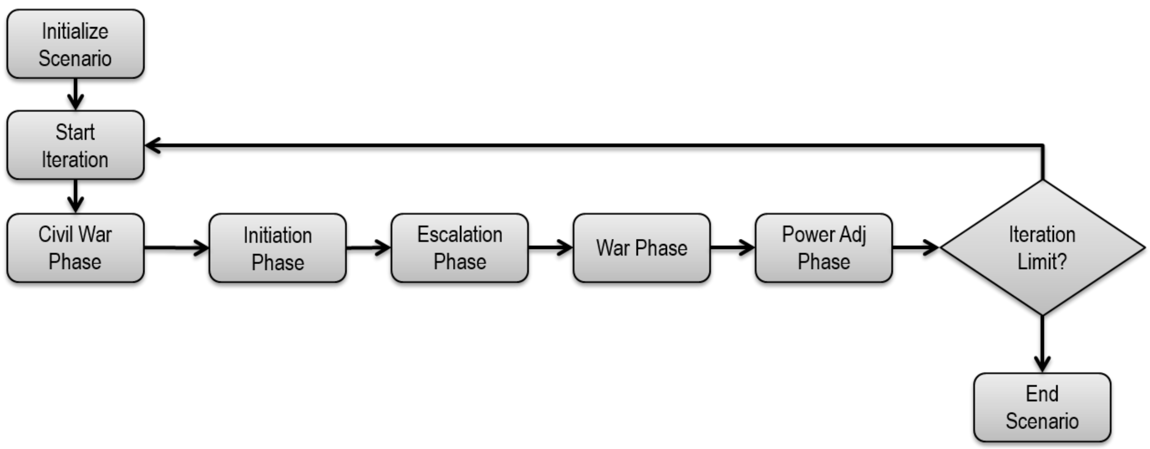

Figure 2.2: Basic RealLand Simulation Process

Civil War Phase The civil war phase begins with a determination whether civil wars may occur and the frequency of their occurrence. Existence and frequency of civil wars are stochastically adjudicated based upon global parameters. When a civil war can occur, each multi-cell state is evaluated for the likelihood of a civil war based upon their ability/decision to pay its empire maintenance costs.[2] Failure to pay the full costs makes the state vulnerable to civil war. The likelihood of a civil war for an individual state is the ratio of the deficit and the total empire costs. Whether a civil war occurs is determined by the draw of a random number against the likelihood of a civil war.

[2]Each new cell acquisition carries a maintenance cost which adds to the overall empire costs. Maintenance costs are determined by distance from the core cell, time in empire, and the cell's power level. Maintenance costs are discussed in greater detail in the description of the power adjustment phase.

The scope or intensity of a civil war is randomly determined based upon the size of the empire's territorial acquisitions ranging from local unrest to complete revolution. The rebelling territories are those cells with the highest maintenance costs. Maintenance costs are determined by distance from the core cell, time in empire, and the cell's power level. The outcome of the civil war is a stochastic process against the likelihood of victory. The likelihood of victory is a function of the power ratio between the state and the rebels. If the rebels are successful, they achieve new statehood as one or more contiguous states. Regardless of the victor, civil war costs are incurred by the state and attacking rebels (Cusack & Stoll, 1990).[3] The phase ends after all civil wars have been assessed and states update their local neighborhoods.

Initiation Phase The dispute initiation phase begins with states engaging in potential target selection for acquisition. For disputes, primitive power seekers and power balancers seek to attack their weakest inferior adjacent neighbor if one exists. However, they may not attack states involved in a civil war during the turn. Rational states will seek to attack their adjacent neighbor that yields the largest positive utility determined by simulating the war outcome in advance.

One aspect of the EARTH tradition is to select the conflict initiators for each iteration. The first step of this selection process is calculating a dispute index or probability of escalation by state. For systems with non-rational actors, the index is the proportion of power in the system contributed by the state. For exclusively rational actors, the index is a function of their expected positive utility divided by the total expected positive utility within the system.

$$Probabilityof Escalation_i = \frac{p_i}{sum_{i=1}^{n} p_i} \tag{2.1}$$

$$Probabilityof Escalation_i = \frac{+EU_i}{sum_{i=1}^{n} +EU_i} \tag{2.2}$$

[3]Details on war adjudication and war costs will be addressed in the war phase description.

Where p is the current power of state i, and n is number of states within the system. EU is the gain in power that the state expects to receive after it simulates the engagement with the target.

Basic RealLand provides three options using this information to determine the initiator(s) for war escalation. The first option is to determine only one aggressor within that iteration. For each state, a random number is drawn and multiplied by the state's escalation index. The state with the maximum resulting value proceeds to the next phase. Here, the most powerful states or the states with the most to gain will be selected more often. The second option is an algorithm that handles multiple initiators in non-rationale systems shown in equation 2.3.

$$Q_i = 2^{3+\frac{p_i - \overline{p}}{s}} \tag{2.3}$$

Where Q_i is the power index for state i, $\overline{p}$ is the average power of all states, and s is the standard deviation of power of all states. A random number is generated between 0 and 31 with those nations with a value over the random number proceeding.[4] Once again, the more powerful the state, the more-likely they are selected as an aggressor. The third form of initiator selection applies only to rational states. Any state with a positive expected utility may initiate a conflict. Additionally, RealLand includes the option for protracted war where states involved in a stalemate during the last turn, must fight again in the subsequent turn. When protracted war is enabled, warring states are automatically selected to continue the engagement.

In the case of multiple aggressors, the system must address the possibilities that states may select the same target or may target each other. The following rules were developed by Duffy (1992) to address the simultaneity of target selection.

[4]These arbitrary values and equation selections seem to be an attempt generate curves to fit the desired behavior... by my observation a practice prevalent in the early days of computing.

1. Both the initiator and its target (another initiator) will withdraw if they find themselves attacking one another.

2. Initiators will withdraw if they are under attack, but will re-engage if they find that they are no longer under attack (e.g. the state that is attacking finds itself under attack).

3. Initiators will withdraw if a less powerful state is attacking their target.

4. States involved in protracted war may not be attacked by new initiators. Alliance formation will occur again as if they were attacking for the first time; however, states may not ally with enemies in the previous turn.

In the Duffy (1992) implementation in a parallel computing environment, states engage in cycles of target selection where some may withdraw during the current cycle only to find another target in a later cycle. The exact re-targeting process for each cycle was not specified. Basic RealLand provides two options for addressing re-targeting. The first option is more consistent with the intent of the conflict dispute phase. The entire state population attempts target selection and then proceeds through the filtering rules. States are not allowed to re-target and once withdrawn, they are not eligible for initiator selection. Thus, the random selection algorithm that selects which countries move forward with conflict escalation includes only legitimate aggressors. The other option is more aligned to Duffy where initiator selection is chosen before targeting and re-targeting is possible. The results of both will be discussed in the analysis section.

Escalation Phase The dispute escalation phase echoes a common pattern of defense wargaming of action, reaction, and counter-action. In this case, it is focused on alliance building as opposed to actual warfighting. The targeted state has the first opportunity to form a defending coalition from the states contiguous with the initiator that is more powerful than the aggressor. If it deems no coalition is necessary or that there is no more powerful coalition, the state will immediately enter a war phase. Otherwise, the state will make a bid to each country within the identified winning coalition. The bid is then evaluated by potential alliance members according to their decision-making logic independently (states do not consider the choices of other states). If the bid is rejected by all potential alliance members, the model immediately moves to the war phase. States that agree to join are now members of the target's coalition and the model moves to the second part of the phase. In similar fashion, if the target grows a coalition that is perceived as more powerful, the initiator responds by attempting to grow a winning attacker coalition with states contiguous to the target. Failure to achieve the desired winning coalition will lead to deescalation as the initiator forgoes the attack. If the attacker is successful in creating a winning coalition, the model will move to the next phase where the target has an opportunity to expand its coalition. Basic RealLand provides the option to allow aggressor states to withdraw at the end of escalation phase after comparing the attacking coalition with the augmented defending coalition. Otherwise, the aggressor coalition is forced into a perceived unfavorable attack. Basic RealLand omits any salience in relationships that transcend the current iteration. However, when protracted war is enabled, states may not ask members of their opposing coalition during the last iteration to join their alliance in the current iteration.

At this point it is worth discussing the three important state decision-making processes in more detail. The first is the formulation of a coalition bid. For non-rational states, Cusack and Stoll (1990) implemented the concept of a minimum winning coalition where states examine the total power of every possible combination of alliance members against the opposing power of the aggressor states. Rational states examine the expected utility in all possible combinations. To calculate expected utility, the state internally simulates the expanded conflict including costs and spoils.[5] A bid is then made for the minimum winning coalition or the coalition that generates the greatest positive expected utility. This second

[5]This algorithm raises performance considerations as the number of combinations is $2x - 1$ where x is the number of potential coalition members. Basic RealLand addresses this performance issue by providing a parameter that sets the threshold for minimum winning coalitions where once exceeded the state will select the first feasible (winning) coalition through random selection. Satisficing was implemented to not only overcome runtime issues in development but also understand the impact of the minimum winning approach on the system.

key decision is to accept or reject an attacking or defending coalition bid. Collective security and power balancers will always join defensive alliances but never join attacker coalitions. Primitive power seekers will only join what they perceive to be winning coalitions. Rational states will join if there is positive expected utility which is determined by internally simulating the conflict from their perspective. The final point is that Duffy's parallel version did not implement concurrency with respect to joining a coalition as states consider bids sequentially until choosing to join a coalition. States may have received multiple bids until they accept a bid.

War Phase The war phase begins by determining an attacker's probability of success. This likelihood of victory (LV) calculation is a function of the power ratio between the attackers and defenders and a shaping parameter *sigma*.[6]

$$LV(t) = \frac{1}{\sqrt{\pi\sigma^2}} \int_{-\infty}^{\ln(t)} e^{-\left(\frac{x}{\sigma}\right)^2} dx \tag{2.4}$$

The function is designed to scale the outcomes giving more or less weight to a power advantage. The smaller the values of *sigma*, the greater the weight of any power advantage. Figure 2.3 illustrates this effect. By design, *sigma* has a significant impact on the war outcome and likewise the model itself as it serves as either an inhibitor or enabler to aggressive states.

[6]There is an important difference between (2.4) and the original formula used by Cusack and Stoll. Specifically, that the *sigma* is squared within the constant. Without this change, the attacker is virtually assured victory despite the power ratio.

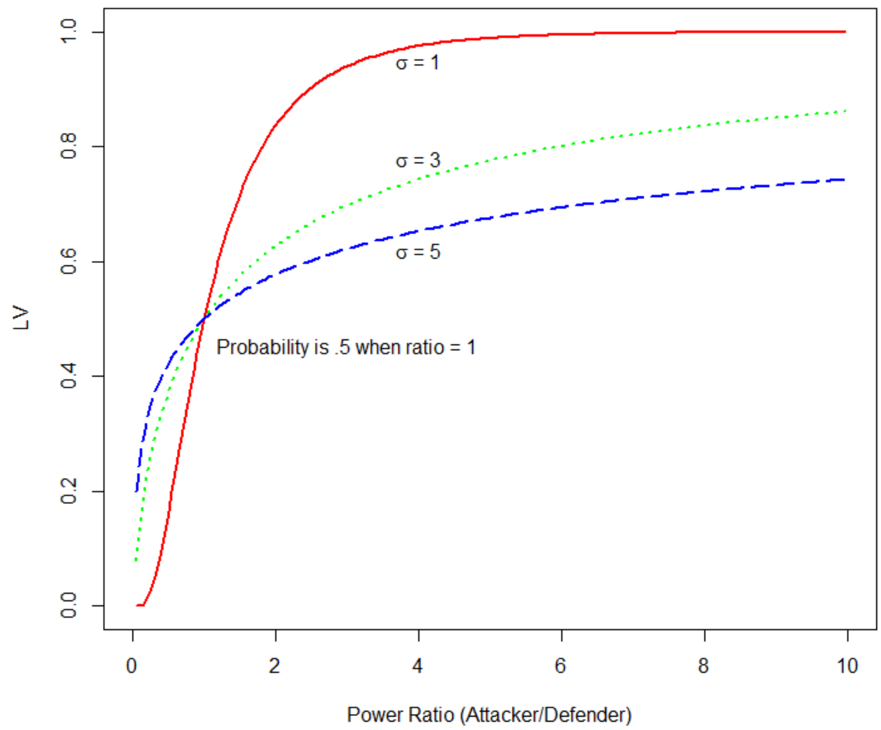

Figure 2.3: Likelihood of victory for varying levels of *sigma*

Once LV result is given, it is compared with a random number. If the result is higher than the random number, the attackers win. If the random number is higher, the defenders win. However, wars can also have indeterminate outcomes. This is an optional feature in the model controlled by the war stalemate parameter (LTPAR). LTPAR controls the likelihood of a stalemate based upon the LV. When LTPAR is set to zero, the model permits only determinate outcomes. Otherwise, the model will first determine the likelihood of a stalemate based upon the LTPAR and the LV.

$$LT = \left(1 - \frac{|LV - 5|}{0.5}\right)^{LTPAR} \tag{2.5}$$

Once calculated, the likelihood of a stalemate is compared to a uniform random number between 0 and 1. If the probability is greater than the random number, the war is considered indeterminate or a stalemate.[7] After the war outcome is determined, war costs and spoils are distributed. All states face war costs regardless of the outcome. War costs may be determined in two ways. The first way assigns a common proportional war cost to warring states.

$$WC = \left(1 - \left(\frac{\frac{\max(p_a, p_d)}{p_a + p_d} - 0.5}{0.5}\right)\right) WC_{max} \tag{2.6}$$

Where p_a and p_d are the combined power of the attackers and defenders and WC_{max} is a global parameter setting the maximum possible cost of an interstate war. Alternatively, a disproportionate function is available that distributes more cost to the weaker side and less cost to the stronger side. A minimum war cost disparity parameter is included for the disproportionate case. Once the war cost is determined, each state is decremented accordingly as the product of the war cost proportion and the state's current power.

$$\begin{aligned} WC_{weaker} &= WC + min\left(random(0,1) \times WC_{max}, WC_{dp}\right) \\ WC_{stronger} &= WC - min\left(random(0,1) \times WC_{max}, WC_{dp}\right) \end{aligned} \tag{2.7}$$

The last step in the phase is assessing the spoils of war in terms of indemnities and territory transfers that only trigger when one side is victorious. Indemnities are taken proportionally from all losing states determined by a global reparations parameter. The parameter controls the percentage of punitive damages defeated states must pay. The captured power is then distributed to the winning states proportionally based upon their power coalition. Territory redistribution is governed by the following rules:

[7] This approach differs slightly from Cusack and Stoll as they had a known error in their notation corrected by subsequent work. This approach was chosen to not favor either the initiator or the target in the calculations. Duffy's alternative approach is the the following: If the realization of the random variable is less than the likelihood of victory and the likelihood of victory is greater than the likelihood of a stalemate, the initiator wins. If the realization is greater than the likelihood of victory and exceeds the likelihood of a stalemate, the target wins. Otherwise, the war results in a stalemate.

1. The likelihood of victory is used to determine the scope of the defeat. For example, if a state has four cells and was defeated with a likelihood of victory of .5, two cells will be ceded to its opponents.

2. Victorious states are rewarded territory proportionally with the most powerful countries selecting first.

3. Territory is only taken from the initiator or the target, no coalition member loses any cells.

4. States select territory based on contiguity and distance to their core cell with a constraint to avoid splitting the losing state (effectively severing the contiguity of the opposing state). Acquisitions that split the state are only taken as a last resort.

5. Selection continues until all territory is redistributed. If a state is called upon during the algorithm and cells are available, the state is guaranteed at least one acquisition.

6. If a state no longer has any hexes under its control, it will be eliminated.

7. If a state is split, the original state retains the cells contiguous to the core cell while a new state forms around the other contiguous clusters.

8. If a core cell of a state is taken, it shifts its capital to the next most powerful cell under its control.

Power Adjustment Phase After all the spoils have been distributed, the power adjustment phase begins. This phase resets all the states to prepare for the next iteration with a few exceptions. The first and most important is the power adjustment. Unfortunately, the implementation in previous versions of the Earth model are not so clear. Cusack and Stoll describe power growth at the cell level where each cell has a unique fixed growth rate determined at initialization randomly by a normal distribution with a mean and standard deviation set by global parameters. Beyond this, their power adjustment equation did not provide the clarity necessary for replication. Several avenues were explored and the results were compared. It is quite likely that only cell agents existed in the original implementation where RealLand incorporates both state agents and cell agents. In the first instance, a state specific parameter growth parameter is applied to its power directly. Cells experience no growth or loss of power throughout the simulation.

$$P_{T+1} = P_T + P_T \times G_i \tag{2.8}$$

Where P_T is the power at time T and G_i is the state specific growth rate.

Alternatively, in the second instance, a cell-based approach was implemented where a state's territories incur the cost and spoils of war in addition to experiencing growth each iteration according to a cell specific parameter.

$$P_{T+1} = \sum_{i=1}^{n} P_{T,i} + P_{T,i} \times G_i \tag{2.9}$$

Where n is the number of cells-controlled by the state and G_i is the cell specific growth rate. Of course, this approach requires distribution of a state's gains or losses to its controlled cells before executing the growth.

Another consideration is the update to each cells' maintenance cost. The maintenance cost is determined as a function of the proportional distance from the cell to core cell of the state, the time in empire, and the cell's power index.

$$c_{ij} = \frac{1}{\sqrt{TE_{ij}}} e^{\frac{D_{ij} - MAXD}{MAXD}} \rho_j \tag{2.10}$$

Where c_{ij} is the cost to state i owning j cell; D_{ij} is the distance between the core cell and state; $MAXD$ is the maximum distance of the world; TE_{ij} is the time the cell has been within the state; and ρ_j is the power index of the cell. Finally, a state must decide their total empire payment and update their current (effective) power for the next iteration of the model. The total empire payment is the sum of the payment required for each cell.

$$EmpirePayment_i = \sum_{j=1}^{n} EPP_i \times (c_{ij} \times GPP) \times CPP_{ij} \tag{2.11}$$

Where EPP_i is the empire specific parameter that determines the portion of empire costs a state will pay; c_{ij} is weighted based upon a global parameter, GPP, that determines the minimum maintenance threshold to prevent a civil war; and CPP_{ij} is the cell specific power perception error which is randomly determined from a normal distribution with a globally set mean and standard deviation. In summary, the state's perceived minimum payment is multiplied by its fixed policy on paying its empire costs EPP_i to determine its total empire payment. The state can decide to pay what it thinks is good, but that may be a mistake. The power adjustment phase concludes when the empire payments are deducted from the states' power. The simulation would return to the civil war phase for the next iteration assuming it has not exceeded its maximum simulation length.

2.1.3 Implementation

Basic RealLand is implemented in NetLogo 5.3.1 with a number of extensions. The R extension requires the statistical package R installed separately and a mildly complicated update to system variables for combined utilization.

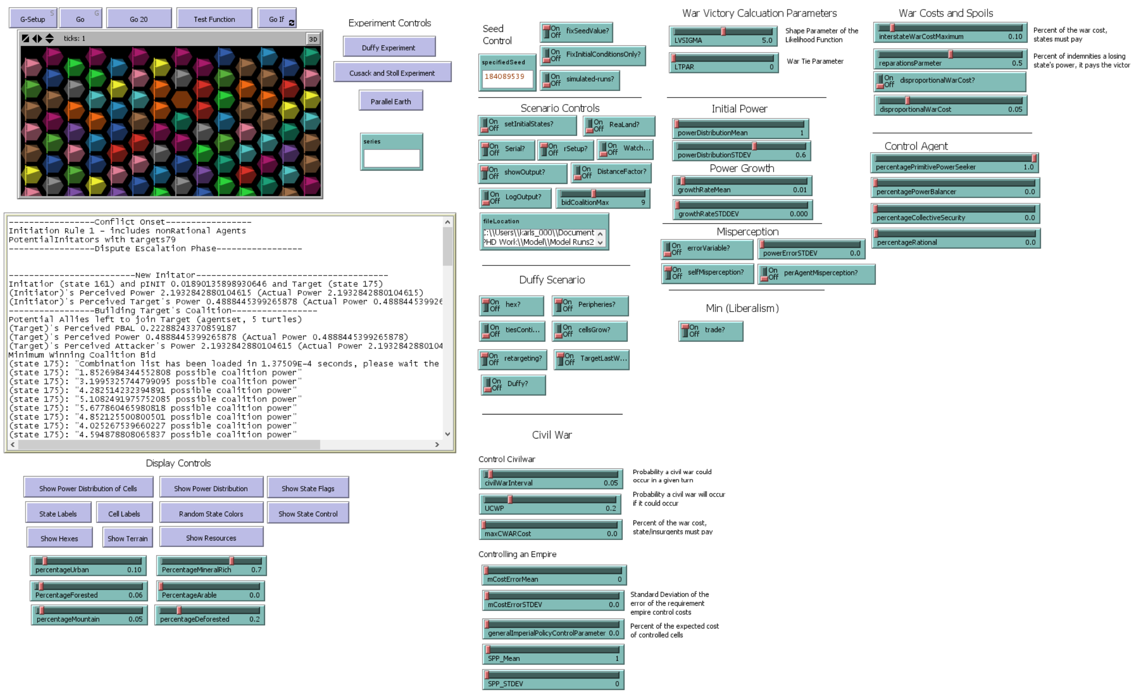

Figure 2.4: Basic RealLand Interface

The R version 3.3.1 was used. This integration allows R functions to be used within Basic RealLand, such as the likelihood of victory calculation requiring numerical integration. For more robust scientific use, another platform emphasizing performance is advisable as a single run can take several minutes especially when allowing the minimum-winning coalition algorithm to go unchecked (observed instances of over 20 neighbors).

2.1.4 Verification

In their main analysis of the EARTH model, Cusack and Stoll (1990) analyze five control factors and three experimental factors. The control factors include the initial power distribution of the states, range of power estimation error, maximum war cost, reparations percentage, and the likelihood of victory parameter. The experimental factors are the variance in growth rates of power, disproportionate war costs, and probability of war stalemates or indeterminate war outcomes. Primitive power seekers were the only states within the system. Civil wars were omitted or turned off for the baseline runs for both EARTH and

Basic RealLand results. Each unique parameter setting is run with 3 separate random seeds. In total, they executed 8748 experimental runs over 12 series. Their results are shown in Table 2.1. The headers show the series number used to indicate the values of the experimental parameter values. The average run length is the length of time to either system collapse or Time 1000. The average run length and proportion of runs ending in a multi-state system are calculated across the experimental runs for that series. The power growth rates, disproportionate war costs, and war stalemates are either included or not across the experimental runs. Cusack and Stoll (1990) distinguished between high values and low values of the LTPAR parameter. The higher the value of LTPAR, the less likely a stalemate.

Table 2.1: Main EARTH Experimental Results (Cusack & Stoll, 1990, p. 106-108)

Series	Average Run Length	Proportion of Runs Ending in Multi-state System	Variable Power Growth Rates	Disproportionate War Costs	War stalemates
20000	613	0.492	No	No	No
21000	760	0.598	No	Yes	Yes (High)
22000	570	0.443	No	Yes	No
23000	776	0.634	No	No	Yes (High)
24000	735	0.587	No	No	Yes (Low)
25000	483	0.24	Yes	No	No
26000	702	0.551	No	Yes	Yes (Low)
27000	587	0.288	Yes	Yes	Yes (Low)
28000	632	0.337	Yes	No	Yes (Low)
29000	460	0.206	Yes	Yes	No
18000	693	0.429	Yes	No	Yes (High)
19000	639	0.369	Yes	Yes	Yes (High)
Mean	638	0.431	-	-	-

EARTH examines two primary output metrics. The first is the presence of more than one state at the end of the iteration. If there is only one, the international system collapsed. The other metric is the time to collapse when one state conquered all others. In other words, did the multi-state system survive and if not, how long did it survive.

Using the serial option of one aggressor per iteration within Basic RealLand, the original design of experiments can be reproduced. The first attempt at comparing Basic RealLand replicates the results of the 20000 series that excluded the three experimental variables as shown in Table 2.1. While Cusack and Stoll (1990) did not analyze this series specifically, the Basic RealLand results are worth some discussion. Figure 2.5 shows the distribution of simulation runs based upon simulation end time. Of the 729 runs shown in Figure 2.5, Basic RealLand showed that 47.3 percent of runs ended in a multi-state system with an average run length 572 iterations.[8] Given the bi-modal distribution, the average duration was used only as an initial point of comparison between runs. A tick is used within NetLogo to represent an iteration of the model or time step. In this case, runs of length 1000 see survival of at least two states while the shorter runs see collapse to a single state.

[8]The number of runs for an experiment was selected by Cusack and Stoll (1990) based upon the 243 different parameter combinations of baseline factors and experimental variables with 3 different random seed values.

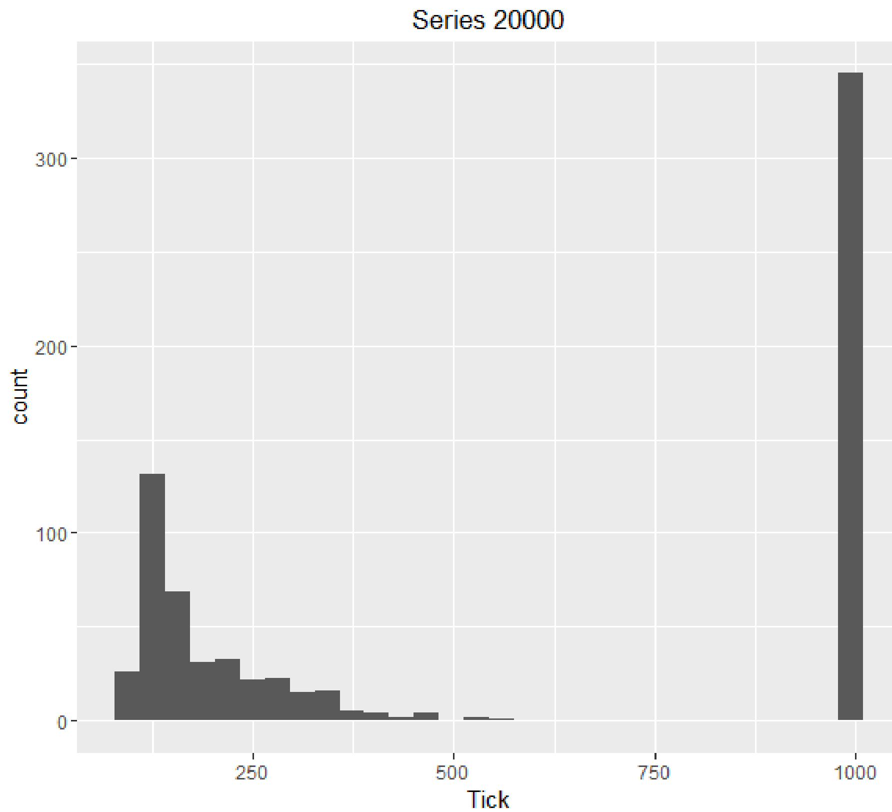

Figure 2.5: Basic RealLand Results for Series 20000

Probit regression analysis, shown in Figure 2.6, was used to examines the factors influencing the probability of system collapse.[9] In Series 20000, three of the five variables are statistically significant at a .001 significance level and one variable, the power misconception standard deviation, only at the .01 significance level. The initial distribution of power standard deviation is not statistically significant though the coefficient indicated that higher values tended towards system collapse. War costs and reparations have a significant negative relationship with system endurance suggesting that higher war costs and punitive spoils lead to a greater likelihood of system collapse. Alternatively, higher values of σ and the power misperception increase system stability. However, as alluded to in an earlier section,

[9] A probit model is appropriate for a binary response. In this case, did the system survive or not to iteration 1000. Logit models were also used, but not displayed here. Tobit models were used when examining time to system collapse as the simulation data has a hard stop at iteration 1000

this result is based upon growth occurring at the state level as opposed to the territory or cell.

```
Coefficients:
                           Estimate Std. Error z value Pr(>|z|)
(Intercept)                -1.65039    0.44356  -3.721 0.000199 ***
interstateWarCostMaximum -6.08802    1.56519  -3.890 0.000100 ***
powerErrorSTDEV             3.68815    1.18517   3.112 0.001859 **
reparationsParmeter        -7.19473    1.22703  -5.864 4.53e-09 ***
LVSIGMA                     0.98530    0.07151  13.779  < 2e-16 ***
powerDistributionSTDEV     -0.21618    0.46511  -0.465 0.642087
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 2.6: Basic RealLand Series 20000 Probit Regression Analysis

As a point of comparison, the series was rerun with growth occurring at the cell level. Of the 729 new Series 20000 runs, 26.5 percent ended in a multi-state system with an average run length of 404 iterations. Figure 2.7 provides the new results showing some considerable differences. Power misperception is not statistically significant and higher war costs have a positive impact on system survival. This suggests that when a state grows in power over time, as opposed to its controlled territory, paying reparations becomes more painful to a state than territorial loss. Similarly, territorial acquisition provides less value with each successive iteration of the model as power shifts from the territory to the state. Conversely, if the territorial cells grow, the value of territory acquisition grows with each successive iteration. Territory acquisition can instantly alter the power dynamics by providing the victorious state not only the original cell's power but the combined growth, spoils, and costs that cell has endured over the course of the simulation run. Under this condition, conquests appear to create such an imbalance that not even significant power misconception deters a conquering state. However, higher war costs have a stabilizing effect as they effectively decrement cell power.

```
Coefficients:
                          Estimate Std. Error z value Pr(>|z|)    
(Intercept)               -3.43616    0.49116  -6.996 2.63e-12 ***
interstateWarCostMaximum   6.18228    1.53678   4.023 5.75e-05 ***
powerErrorSTDEV            0.82782    1.17541   0.704    0.481    
reparationsParmeter       -4.66475    1.19661  -3.898 9.69e-05 ***
LVSIGMA                    0.74316    0.07002  10.614  < 2e-16 ***
powerDistributionSTDEV    -0.42232    0.46857  -0.901    0.367    
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 2.7: Basic RealLand series 20000 (Cell Growth) Probit Analysis

Comparing the results for state and cell growth in the baseline Series 20000, proximity to the results of Cusack and Stoll (1990) is best achieved when power is retained with the state agents. Remaining experiments are executed with the power retained at the state agents. This is further described below in the analysis of the Basic RealLand model.

Basic RealLand also incorporated some features from Duffy (1992) as described above. Duffy used parallel processing to simulate true simultaneity between agents having multiple conflict initiators within the same iteration. Basic RealLand does not reflect true concurrency; rather agents, when called, are processed sequentially in a random order. This approximation seems valid given the details of Duffy's implementation which was primarily focused on improving the run-time when using multiple initiators. Duffy's core experimental results are shown in Table 2.2. The peripheries indicate whether or not world wraps around like a sphere. If peripheries are enabled, some states will live on the edge of the world with less neighbors than the other states.

Table 2.2: Concurrent EARTH Results of System Endurance (Duffy, 1992, p. 260-261)

Study	System Endures	Peripheries	Misperception	Self-Misperception	Protracted Wars
A	0.965	Yes	Constant	Yes	No
B	0.023	No	Variable	No	Yes
C	0.453	No	Constant	Yes	No
D	0.429	No	Constant	Yes	Yes
E	0.020	No	Variable	No	No

Perhaps the most important point of concern in the previous study is that Study A was able to achieve high-levels of system endurance despite relatively low values of σ. For each run, σ was pulled from a distribution with a mean of 1 (which would yield victory for the stronger state 84 percent of the time) and a .3 standard deviation (σ is the primary input into the equation 2.4 which provides the LV). At a σ value of .70, the chances that a state with twice the power achieves victory is .92. At three times the power, it is .98. The point is that the stronger coalition almost always wins. These results grow more questionable when Duffy discusses a new study F with a σ of .25 and a .083 standard deviation. At this level, the victory result is near deterministic when power is 40 percent greater than the opposition. Under these conditions, the serial case would almost never yield a multi-state empire. One could conclude that the implementation of the likelihood of victory equation wrongly incorporated $\sqrt{\sigma}$ as described in his documentation, but that remains untested.[10]

Another interesting finding is the drastic difference in the results of Study A and Study C where the only factor is the presence of peripheries in Study A and a torus structure in Study C. This finding seems counter-intuitive for the same reason that Duffy provided in justifying the negligible impact of a larger grid of squares. The initial decline in the number of states tends to have a normalizing effect on variations in the initial conditions. This is evidenced by the statistically insignificant impact of the initial power distribution among

[10]The documentation error is described in more detail later.

states in the serial iteration.

The first set of Basic RealLand results are provided in Table 2.3. Each study was comprised of 256 runs with parameters pulled from the same distributions as described by Duffy (1992).

Table 2.3: Basic RealLand Results (No Re-targeting)

Study	System Endures	Peripheries	Misperception	Self-Misperception	Protracted Wars
A	0.792	Yes	Constant	Yes	No
B	0.512	No	Variable	No	Yes
C	0.746	No	Constant	Yes	No
D	0.746	No	Constant	Yes	Yes
E	0.582	No	Variable	No	No

Studies A, C, and D provided similar results with a constant misperception rate defined in the initial conditions. Studies B and E were similar with a variable rate where it updates each turn. This is intuitive as a constant error rate tends towards a static equilibrium where the initiator states are dissuaded from further attacking (I may always perceive my opponent as being much stronger than it actually is). The power calculations can change significantly with each iteration as the error rates vary which prevents any stabilizing equilibrium. The lack of re-targeting adds another artifact: the more powerful states will withdraw from attacking a weaker state, the weaker states are less likely to be selected, and even if selected, the target will ask the larger more powerful state to ally, often defeating the attacker's initial will to attack. If the more powerful states are allowed to re-target, the expectation is that it would remove the artifact. Results of probit and tobit analysis for Study A, yielded only one factor of weak statistical importance. The rate of power misconception was deemed significant at the .05 level, suggesting that the greater the misperception range, the less likely the multi-state system is to endure. These results contradict the serial finding described in the previous section, though there are enough conceptual differences to question the meaning. When re-targeting is incorporated, a large majority of runs quickly devolves into empires regardless of the presence of peripheries, misperception, self-misperception, or protracted war. When the more powerful states are selected to attack, growth occurs at the cell, and in an environment with relatively low values of σ, this is to be expected. Reproducing the results of Study A, C, and D remains elusive and a definite stance requires additional testing beyond the scope of this effort.

2.1.5 Validation

As a replication, any validity of Basic RealLand is inherited through the EARTH tradition and will not be addressed in detail here (Bremer & Mihalka, 1977; Cusack & Stoll, 1990; Min, 2002).

2.1.6 Analysis

In executing the complete baseline of results from Cusack and Stoll, shown in Table 2.1, further evidence confirms my decision to retain power with the states particularly when examining the proportion of runs ending in a multi-state system. Incorporating only disproportionate war costs, Series 22000 provides what can only be described as the same result. Similarly, Series 25000 yields essentially the same proportion with a longer average duration when including only the variable growth rates. The key difference is demonstrated in Series 23000 and 24000 that included the war stalemate parameter only. Due to known errors in the original documentation, Basic RealLand implemented a different algorithm that favored neither the initiator nor the target. Correspondingly, the results show that the incorporation of war stalemates has less impact on system stability than the previous study. This appears to be a function of error in the original study, but this remains untested.

Table 2.4: Basic RealLand Results with () indicating the difference of the result and the result shown in Table 2.1

Series	Average Run Length	Proportion of Runs Ending in Multi-state System
20000	572 (-41)	.473 (-.019)
21000	662 (-187)	.562 (-0.036)
22000	547 (4)	.450 (.007)
23000	674 (-201)	.554 (-.080)
24000	632 (-159)	.509 (-0.078)
25000	466 (94)	.231 (-0.009)
26000	623 (-124)	.513 (-0.038)
27000	531 (-8)	.281 (-0.007)
28000	578 (-52)	.358 (0.021)
29000	427 (121)	.177 (-0.029)
18000	617 (-111)	.383 (-0.046)
19000	559 (-56)	.316 (-0.053)
Mean	574 (-64)	.401 (-.03)

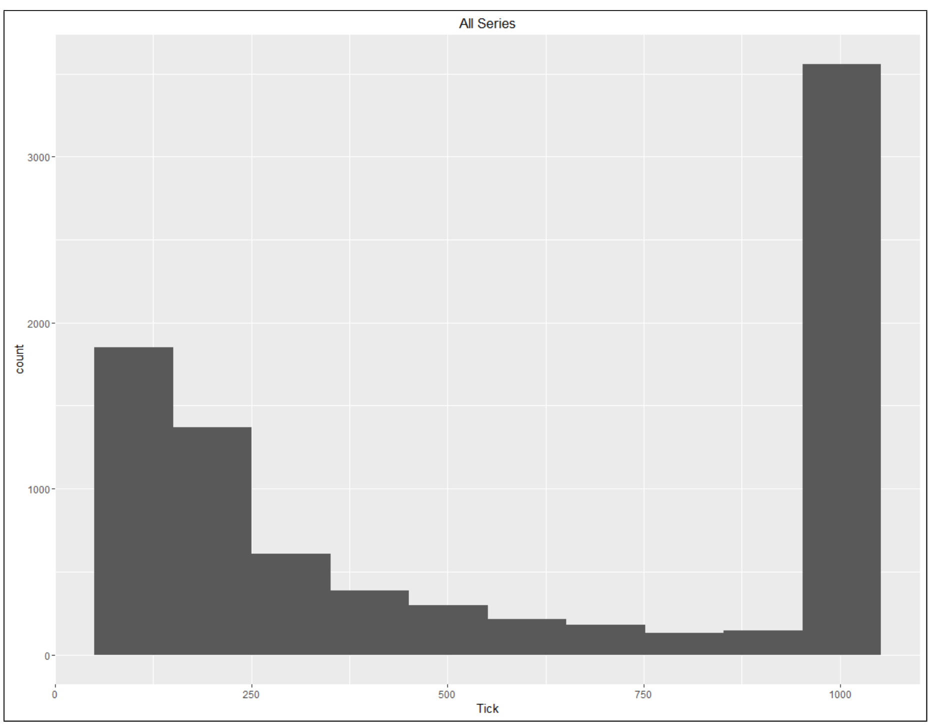

Figure 2.8: Basic RealLand Run Length Distribution for All Series

For the complete results, probit and logit regression are used for the dichotomous response outcome of system survival shown in Figure 2.9 and Figure 2.10. Additionally, tobit regression analysis, shown in Figure 2.11, examines the factors affecting the system duration with the simulation arbitrarily truncated at 1000 iterations. As in the analysis of Series 20000, the variance of initial power allocation or distribution is not statistically significant implying that the relative power at start time has no statistical impact on system endurance to iteration 1000.[11] This is consistent with the results of Cusack and Stoll (1990) where the initial power distribution was shown to be the least important of the eight parameters and statistically insignificant. Another area of agreement is punitive damages with ReaLand showing that the system has less chance to endure as the victors gain more spoils. The most significant parameter in both this study and the previous studies is σ which controls the relationship between the states' power ratio and the likelihood of victory. With higher values of σ, more power advantage is required to achieve a nearly assured victory as there is more variance in the outcome. This has the effect of preventing the victory of a powerful state by chance alone. In other words, the higher values increase the chances of a lucky win by the weaker state.

Areas of disagreement among baseline variables include both war costs and power misperception error which were first discovered when comparing state vs. cell growth implementations. Cusack and Stoll (1990) determine that power misperception was statistically insignificant (though higher values lead to more system stability) and higher war costs have a counter-intuitive effect of increasing system endurance. They state that most realists believe that greater the war costs, the less likely the system will survive. Basic RealLand confirms the theoretical perspective. As demonstrated above, the cell growth implementation has similar behavior on these two variables with Cusack and Stoll (1990) while the state growth does not.

[11] This is also a function of the limited range of power inequities within the system that were tested in the experimental runs. One can guarantee a significant result if a super power was placed within a population of weak states.

The relationship of experimental variables within this study and the previous study are in alignment. In both studies, including variable growth rates or disproportionate war costs, significantly decreased system endurance. Growth rate variance was the second only to the σ value in its effects on the system. Finally, the likelihood of a stalemate also had a significant positive impact in both studies, though greater for Cusack and Stoll for reasons already discussed. In summary, six of the eight parameters exhibited the similar impact on the system and differing two are explained by an implementation of power growth and adjustment at the state agent or the territory.

```
Coefficients:
                           Estimate Std. Error z value Pr(>|z|)    
(Intercept)              -1.617e+00  8.774e-02 -18.427  < 2e-16 ***
interstateWarCostMaximum -5.777e+00  3.201e-01 -18.046  < 2e-16 ***
powerErrorSTDEV           2.763e+00  2.161e-01  12.783  < 2e-16 ***
reparationsParmeter      -2.473e+00  2.155e-01 -11.476  < 2e-16 ***
LVSIGMA                   7.038e-01  1.349e-02  52.174  < 2e-16 ***
powerDistributionSTDEV   -6.292e-02  8.456e-02  -0.744  0.45684    
disproportionalWarCost   -1.554e+00  5.384e-01  -2.886  0.00391 ** 
LTPAR                     8.459e-02  8.553e-03   9.890  < 2e-16 ***
growthRateSTDDEV         -1.979e+02  7.422e+00 -26.658  < 2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 2.9: Basic RealLand Comprehensive Probit Analysis

```
Coefficients:
                          Estimate Std. Error z value Pr(>|z|)    
(Intercept)               -2.78378    0.15596 -17.849  < 2e-16 ***
interstateWarCostMaximum -10.41303    0.57069 -18.246  < 2e-16 ***
powerErrorSTDEV            4.90126    0.38284  12.802  < 2e-16 ***
reparationsParmeter       -4.34518    0.38100 -11.405  < 2e-16 ***
LVSIGMA                    1.22555    0.02601  47.114  < 2e-16 ***
powerDistributionSTDEV    -0.10466    0.14871  -0.704  0.48158    
disproportionalWarCost    -2.56951    0.94437  -2.721  0.00651 ** 
LTPAR                      0.14981    0.01510   9.919  < 2e-16 ***
growthRateSTDDEV        -351.71020   13.47208 -26.107  < 2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 2.10: Basic RealLand Comprehensive Logit Analysis

```
Coefficients:
                          Estimate Std. Error z value Pr(>|z|)    
(Intercept):1            1.977e+02  2.055e+01   9.618  < 2e-16 ***
(Intercept):2            5.853e+00  1.037e-02 564.518  < 2e-16 ***
interstateWarCostMaximum -1.464e+03  7.358e+01 -19.899  < 2e-16 ***
powerErrorSTDEV          5.351e+02  5.095e+01  10.502  < 2e-16 ***
reparationsParmeter     -7.520e+02  5.103e+01 -14.737  < 2e-16 ***
LVSIGMA                  2.498e+02  2.747e+00  90.944  < 2e-16 ***
powerDistributionSTDEV  -2.114e+01  2.021e+01  -1.046 0.295691    
disproportionalWarCost  -4.361e+02  1.242e+02  -3.510 0.000448 ***
LTPAR                    2.938e+01  2.023e+00  14.520  < 2e-16 ***
growthRateSTDDEV        -3.419e+04  1.669e+03 -20.489  < 2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 2.11: Basic RealLand Comprehensive Tobit Analysis

```
                             Response        Tick
powerDistributionSTDEV   -0.005373566 -0.00728579
reparationsParmeter      -0.088852996 -0.10320361
powerErrorSTDEV           0.100281035  0.05979933
interstateWarCostMaximum -0.172695814 -0.14790411
disproportionalWarCost   -0.092060470 -0.09012908
LTPAR                     0.076894976  0.10340943
growthRateSTDDEV         -0.223709624 -0.11449575
LVSIGMA                   0.592829478  0.74505825
```

Figure 2.12: Basic RealLand Correlation Matrix

At this point, it is important to recall that the original study had two key logic errors in the documentation and a clarity issue in another. The first area was in the mathematical notation, provided by Cusack and Stoll, mistakenly inflates the likelihood of victory. If true, this error would enormously favor the victor. Based on the results above, this error can be dismissed as a typo. The other error is not so clear as it affects the victor determination where the target is inordinately favored as written, but again this error can be largely dismissed as well. Some form of outcome determination was implemented that could have biased the results towards the target when war stalemates are allowed in the system. However, the results do not appear greatly affected. The more substantial issue is the lack of clarity in whether power growth and adjustment is handled at the state or its controlled territories. Cusack and Stoll (1990) provide mixed signals that could suggest that power exists at the cells, but they discuss the distribution of war costs and spoils at the state agent level. Despite these issues, the similarity between two independent implementations is striking and provides further reinforcement for many of their initial conclusions.

Summarily, the goal of this section was to yield evidence of verification through independent replication and build a foundation for Enhanced RealLand. This is accomplished by Basic RealLand. Cusack and Stoll (1990) did provider further analysis on alliances, geographic position, decision-making logic, and civil wars, but those elements will be subjects for future exploration.

2.2 Enhanced RealLand

2.2.1 Motivation

Enhanced RealLand embraces the wargaming tradition as a means of traversing the space between gross abstraction and emulated realism. Enhanced RealLand has similarities with Basic RealLand in objective, but it is a completely separate model. Agents have control not only over their territory but of discrete military forces of different types and functions. Enhanced RealLand uses agents based on the conflict-theory model of strategic decision-making. The agents face decisional conflict that ultimately affects their information processing and subsequently their decision-making. Agents may invest in their economy and military industrial complex, trade and form temporary alliances, re-position forces, and make war against other players. As opposed to Basic RealLand, Enhanced RealLand agents are intended to mirror how human players would engage within the simulation. The motivation of Enhanced RealLand is to provide a proof of concept for a wargaming approach for computational IR to better explore international conflict. As a new model, the analysis is primarily concerned with the impact of noise, parameter variation, and varying initial conditions affecting the structure of the international system.

2.2.2 Design

Structure

In Enhanced RealLand, the players are strategic decision-makers represented by computer agents. The term *players* is chosen both to differentiate it from Basic RealLand's use of *states* and to better describe the entity that the agent represents. At the start of the simulation, players control a randomly initialized set of territory and resources. They are also given a normally distributed risk tolerance. The risk tolerance is a way to characterize a player's emotional arousal threshold. The greater the risk tolerance, the less sensitive it will be to small changes within environment. A player's objective is to increase the national power of his country and remain in office.[12] The structure of Enhanced RealLand is based explicitly upon the RealLand theoretical framework. A player must grapple with internal and external considerations to formulate a strategy that meets foreign and domestic agendas. A key distinguishing element of the model is the representation, albeit simplified, of military units. Military forces may be purchased, deployed, and employed to accomplish

[12]Internal dynamics is currently an area for future direction but the description is fairly robust so I have included it within the description of the model. It is implemented within the model but needs additional design and verification.

player goals. This section will review the environment, the players and their interactions.

The Environment Enhanced RealLand uses a recognizable spatial environment incorporating common geographical features as shown in Figure 2.13. The artificial world can be generated by two different implementations. A continental landmass can be randomly created based on a range of parameter settings specifying the percentage mountainous, urban, etc. While a more earth-like configuration is possible, Mearsheimer (2014) placed an emphasis on land power that served to scope the complexity within Enhanced RealLand.[13]

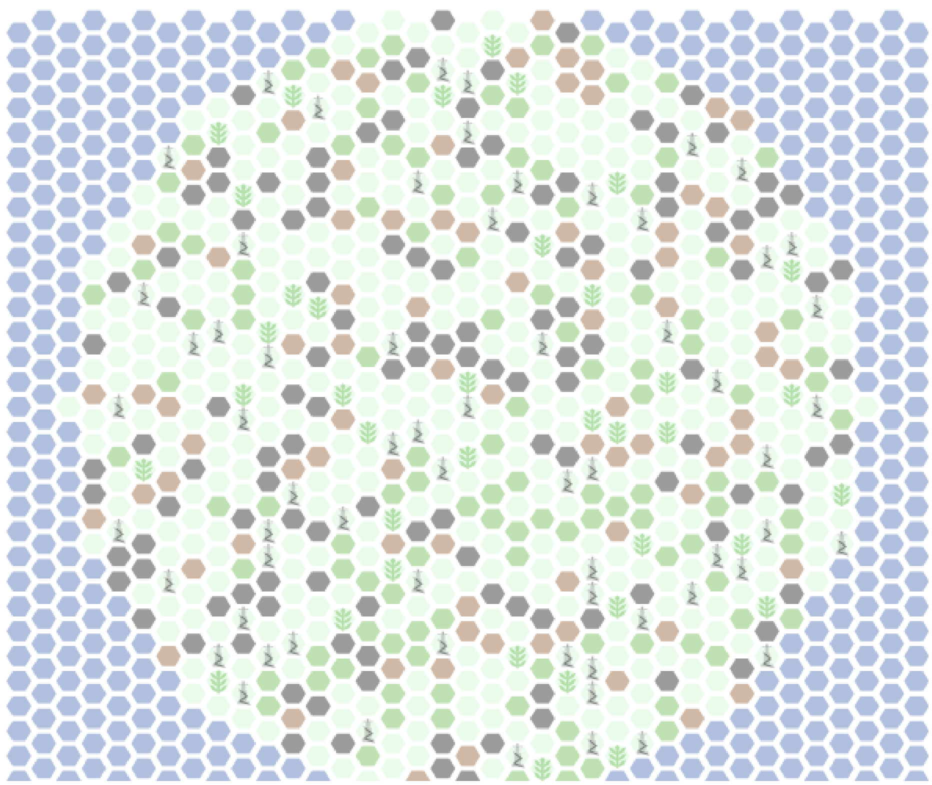

Figure 2.13: Enhanced RealLand Spatial Environment Terrain View

[13] Alternately, a ruggedness factor is used to determine mountainous terrain based upon the implementation (Corr, 2002). The ruggedness factor generates a relationship between adjacent hexes so terrain progressions are more natural (i.e. mountains are next to hills). Both were incorporated as a means to compare the outcomes from a randomly generated geography and a more realistic one. Additionally terrain shaped on a portion of the Korean peninsula is also available.

In either case, the hexes are defined by terrain type. The standard for wargames is usually clear, mountain, forest, urban, sea, and lake types as strategic terrain. Figure 2.13 shows sea terrain as blue, urban terrain as gray, forests as green, mountains as brown, and clear as light green denoting flat or rolling terrain. Terrain is a strategically relevant feature within Enhanced RealLand due to its impact on the movement and combat strength of military units. In Enhanced RealLand, terrain yields defensive bonuses and offensive decrements for military operations. An armor unit attacking from a forest will have its combat power halved. Its target sitting in a mountainous or urban region will be doubled on defense. Rugged terrain provides enhanced protection for defenders and obstacles for attackers.[14]

Additionally, Enhanced RealLand aggregates natural resources into two discrete elements. The first is industrial raw materials represented by oil wells. In the model, oil is needed to fuel the military industrial complex. The second is agricultural materials symbolized by wheat shocks. Wheat is a necessary input to provide food security for cities as well as the manpower to generate military capability. A city with food insecurity will not contribute to the military industrial complex. Each clear hex may contain an oil or a wheat. Oil may be stacked within a hex up to 3.

Production centers are the military industrial complex representing the combination of population, industry, and natural resources. Production centers may only be located in cities. A production center has a value indicating both output capacity and technical capability of the center. A player may have one or more production centers within its cities. Military technology is determined by the highest value of the production centers. The greater the value is; the more sophisticated military capability can be produced.

[14]Terrain effects on combat are implemented but movement effects remains under development as I explore better ways to traverse ground units. Enhanced RealLand also introduces rivers, shown as blue lines, as natural barriers for defenders. A river is implemented to flow from higher elevations into sea terrain. Defending units are doubled on defense when being attacked by units on a river hex. Rivers are generated but currently have no functionality as either obstacles for movement or combat. Enhanced RealLand also incorporates a railroad transportation network, shown as red lines, that connect cities. This network impacts military mobility and logistics. Roads are partially implemented. Roads are used for the positioning of reactionary forces, but railroad units have not been fully constructed.

Production centers produce production factors. For a production center to produce its value of production factors, it must be mated with an equal number of oil. If a player has a shortage of oil, this represents a serious economic disadvantage. Countries which trade for resourced production factors cannot produce anything beyond the capability of their own production centers.

Territorial control is not absolute as hex territories may be contested and conquered by other players. Benefiting from any captured territories, players may seek out wheat, oil, cities, and production centers as means of increasing their own national power. Players failing on the domestic front due to insufficient resources may find themselves with a dissatisfied, angry population that leads to revolution. In either case, losing territory poses a significant problem for the affected player's ability to generate national power and remain in control of their country.

The only means of directly controlling another player's territory without their concurrence is through military operations. This could be as simple as advancing into another player's unprotected territory or through a significant kinetic engagement on the border. Enhanced RealLand arrays players with a simplified range of generic military capabilities.[15]

Ground Forces. Within Enhanced RealLand, there are four types of ground forces. The first type is basic infantry (INF) with a movement rate of 2 hexes per turn. INF units can be no greater than 2 combat factors. The second type is mechanized infantry (M INF) with a movement rate of 4 hexes per turn. M INF units can be no greater than 4 combat factors. The third type is armor (ARM) which have a movement rate of 6 hexes per turn. ARM units can be no greater than 8 combat factors. Because of ARM units' ability to mass

[15]The objective was to add sufficient resolution to prove the concept while avoiding a significant amount of coding. My ambition was to build all the generic unit types from attack helicopters to stealth bombers to cruise missiles with precision guided munitions (PGMs). However, Netlogo's turtle shapes editor was not designed for handling military force structure and the coding demands would be beyond the scope of this level.

offensive force, it is considered a force projection capability. Only three ground combat units may be stacked in a hex. Generic air defense units may be purchased to provide protection against fighters and bombers. They have a movement factor of two hexes per turn and have no stacking restrictions. Air defense units have a combat radius of 4 hexes. Additionally, ground units have a zone of control that extends to adjacent cells. An opposing unit can advance into a zone of control during a turn, but cannot continue. Artillery, marines, airborne infantry, and ranger (special forces) units have not been included.

Air Forces. Within Enhanced RealLand, there exists only interceptors, fighters, and bombers. Stealth, military transport, medium-range bombers, fighter-bombers, anti-radar fighters for SAM suppression, attack helicopters, and cargo helicopters have not been included. Interceptors (INT) are used by poor countries to perform defensive combat air patrols (DCAP). They have a combat radius of 20 hexes. Fighters (FTR) and strategic bombers (SAC) provide force projection missions by sweeping away DCAP and striking enemy forces or infrastructure. Fighters can range 30 hexes and bombers are assumed to range the entire game board. An airbase reaches maximum capacity with 12 factors of air units. Multiple airbases may be constructed.

Irregular Forces. Guerillas are incorporated into Enhanced RealLand as a result of either internal instability or as resistance forces forming outside of conquered cities. In the case of an insurgency, guerillas will be associated with the new insurgent state.[16]

Naval Forces. No naval forces have been included within Enhanced RealLand. Naval strike groups, military sea transport, amphibious landing craft, ASW aircraft, submarines, and small fast attack vehicles have not been included.

Missile Forces. Missile forces are not included within Enhanced RealLand. This includes ballistic missiles, anti-ballistic missile defense, and a wide variety of cruise missiles

[16] As previously mentioned, the internal dynamics is considered an aspect of future direction.

with precision guided munitions.[17]

Space Forces and Recon Aircraft. As uncertainty of information is not the focus of Enhanced RealLand, these capabilities were not included. In Enhanced RealLand, players are limited in their information processing based upon their internal decisional conflict, not through military deception techniques.

Transportation. Players can build railroad units that traverse the network. Each RR unit represents the number of trains required to transport 8 factors of ground units. Units may move to a rail line, be picked up by the railroad, and be offloaded at other location. Railroad movement is 30 hexes after loading and unloading penalties.[18] Truck transportation is not included.

The Players Enhanced RealLand players are modeled in accordance with the conflict-theory model. As such, players have two major functions. The first function is perception where players sense the environment. In Basic RealLand, this algorithm was confined to the power of neighboring states and potential alliance members. Enhanced RealLand expands perception to include a range of opportunities and threats. The second function is the decision-making process where players formulate strategies. The player must assess available information and select a course of action. There is no information hiding or obfuscation.

As described in the RealLand framework, players have a set of considerations. In Enhanced RealLand, internal considerations include the probability of holding office, validators' satisfaction, and the decision latitude.[19] External considerations are comprised primarily of the status and employment of military forces by other players as well as the general power

[17] I resisted the temptation to add intercontinental ballistic missiles (ICBM) with nuclear warheads and anti-ballistic missile defense into Enhanced RealLand until I prove the basic structure of the model. These are all capabilities to add in further explorations as further confounding factors.

[18] This has not been fully implemented and railroad units have not been included within the analysis.

[19] The calculation logic has all been implemented, but I have to verify the issue handling. This will be discussed in future directions.

ratios. Every turn, players examine the world for changes in the international system. Enhanced RealLand views these realities as potential issues for the players to address during strategy development. Issues are always new to the turn, but the players will track that the same issue has occurred for multiple turns.

External Considerations. External considerations are primarily measures of the behavior and disposition of other players. The following are questions a player considers each turn:

- *Are my neighboring players increasing their forces on my border? Is this a trend?* The augmentation of border forces could be seen as an escalating move similar to the initiation of a dispute in Basic RealLand. However, in this case, the opposing player may only be attempting to satisfy their validators' demands for border security. Judgment on what to do will occur in the strategy phase.

- *Are foreign forces present on my border in a neighboring country? Are there any foreign forces with presence in a neighboring country at all? If so, are they at war or allied with the neighboring player? Are the forces increasing over time?* Foreign forces in any neighboring country will remain a significant concern. Either a player has invited them in for defense, they are transiting to another state, or their presence is the precursor to an attack on a neighboring state. In either case, it will generate an issue.[20]

- *Are there any rising or retreating powers in the world? How are my alliances doing? Is my power declining?* While the overall power balance factors into a player's internal considerations, the trend analysis is an external factor. An increasingly powerful, yet still weaker, neighbor could be a target of a preemptive strike. National power is defined in Equation 2.12. It is the normalized sum of a country's oil, wheat, production

[20]This issue has not been fully implemented. Foreign forces can be detected, but the nuances have not been implemented.

factors, cities, area, and combat factors.

$$p_i = \frac{O_i}{\sum_{i=1}^{j} O_j} + \frac{W_i}{\sum_{i=1}^{j} W_j} + \frac{PF_i}{\sum_{i=1}^{j} PF_j} + \frac{C_i}{\sum_{i=1}^{j} C_j} + \frac{A_i}{\sum_{i=1}^{j} A_j} + \frac{CF_i}{\sum_{i=1}^{j} CF_j} \quad (2.12)$$

- *What players have force projection capability (i.e. fighters, bombers, and armor)? Is it growing? Do they have resource demands? Do they need resources?* Players with increasingly more force projection capabilities and resource demands are potential threats that may require balancing alliances, or they may be potential allies against another neighboring player.

- *Am I currently at war? Am I winning?* Defensive wars and alliance requests always generate an issue for the strategic decision-maker. Whether a player is winning is based upon the gains and losses since its last turn and any changes to the force balance. War is currently limited to neighboring players as players cannot yet send forces and perform military operations anywhere on the artificial world.

Player Decision-Making Enhanced RealLand computer players are directly informed by the work of Janis and Mann (1977). Consequently, players may experience stress that negatively or positively affects their information processing capabilities. Stress is a function of the perceived magnitude of the issue, ability to find a mitigating or opportunistic strategy, and time to address the situation. Enhanced RealLand computer players are unfortunately not quite that human so each issue has been characterized into situations that lead to the coping patterns described in the conflict-theory model. Issues are placed upon the strategic decision-maker's desk. Each turn players engage in desk clearing by sorting through each issue. All issues will be examined, but not all will warrant a response. During the next turn, players will ask the same questions potentially generating some of the same issues. Enhanced RealLand tracks the duration of reoccurring issues. Players ask the following chained questions with respect to each issue.

1. *Are the risks serious if I don't change?* If a player answers no to this question, they will exhibit a pattern of unconflicted adherence and move on to the next issue.

2. *Are the risks serious if I do change?* If no, the player will have unconflicted change and accept the first solution that presents itself. The longer the issue has been on the desk, the more likely the decision-maker will answer in the affirmative.

3. *Is it realistic to hope to find a better solution?* If no, the player will delay taking action and proceed to the next issue. A better solution is a feasible solution within Enhanced RealLand that has a chance to improve the player's considerations for the next turn. For instance, the weakest player with nothing to trade will have few options.

4. *Is there sufficient time to search and deliberate?* If no, the player becomes hypervigilant. If in hypervigilant mode, the player will be more prone for rash actions. If yes, the player is vigilantly processing information and will attempt to maximize their long-term strategy in handling the issue.

Players face complex situations where they must make personally consequential decisions and live with the consequences. Enhanced RealLand applies a descriptive model of strategic decision-making that alters how the decision-maker responds to an issue depending on decisional conflict. The implementation details will be discussed in the strategy phase description.

The Interactions Unlike the EARTH tradition, players have a diversity of options in internal investment, trade, alliances, forward positioning, and military operations bounded by real-world operational conditions. A distinct difference is that the desire to use military force is not inevitable. Players may conclude that not using force is the best way to advance their national power. War is not a specific action, but a descriptive term that applies to sustained military operations with some intensity between countries. Military operations are disaggregated into air, land, sea, and space domains. In Enhanced RealLand, the focus is on land power, though some air power is included, consistent with offensive realism

(Mearsheimer, 2014). The other domains are excluded. Status across the domains affects a player's overall effectiveness in the use of military power. Players with offensive air power will have a significant advantage over players that have none.

Internal Investments. Players can interact internally in their country in a number of ways by spending production factors during a production turn. This turn occurs periodically based upon a global parameter where players receive planned military acquisitions and submit plans for future acquisitions. Production factors are the currency, when supplied with oil, to be used in advantageous ways. Internal investments are made during a production turn to realize benefits at the next production cycle. This requires players to commit to acquisitions that are realized in the future. The following are the types of investments that a player may make during a production turn.

- *Development of military strength.* To field military capability, a production factor is combined with a city, resourced with a wheat, to produce one combat factor of military strength. The cost in production factors of the unit will vary depending upon the level of sophistication.

- *Increase a production center.* A player may advance production centers to the next level. The more advanced weapon systems require higher production center values.

- *Develop a new production center.* New production centers can be built in a player controlled city.

- *Discover new raw materials.* New agricultural areas or oil fields may be attempted. The result is stochastic depending upon the terrain conditions.

- *Stockpile.* Production factors can be saved unspent to be used at the next production cycle.

Actions: Trade, Alliances and Military Operations. After players have decided to seek a trade for wheat, oil, or production factors, they will propose a trade to their preferred trading partners. In Enhanced RealLand, trading is in accordance with the zero intelligence trader model. The zero intelligence trader model is a simple economic system where buyers and sellers propose prices randomly, subject only to minimal constraints. In this case, players will not trade below their minimum requirements of wheat and oil.[21]

Alliances exist only as long as it is convenient for all parties. Alliances are defensive or offensive in nature. Standing alliances are only between neighboring players or on the occasion a powerful player is willing to station forces in a weaker player's country. The benefit of a standing defensive alliance is to reallocate border forces from an allied border to a more threatened region. The benefit of a standing offensive alliance is to position forces forward to attack another player. All other alliances are considered ad hoc pleas for support to counter an aggressive player.[22]

Players may conduct three types of military operations. The first is a ground attack where their border forces engage the enemy border forces. If the enemy forces are either destroyed or pushed back, the attackers may advance and seize the territory (creating a new border). The new borders are then updated to continue the engagement the next turn. The second is strategic strikes where bombers may be used to deplete ground forces or degrade airbases if air defenses have been neutralized by fighter aircraft. The third is air superiority which includes both offensive and defensive air. Air defense units are included in the air superiority mission.

Dynamics

Enhanced RealLand simulates the interaction of players over time as they react to societal pressures and the actions of the other states. This section describes the phases within a

[21] If a player has no resources to trade or its preferred trading partners have no resources to sell, a player could attempt to trade a production factor for the given desired resource. For instance, a state with limited oil but high production might trade a production factor for multiple oil. However, this has not been implemented.

[22] Currently only ad hoc alliances are implemented. Handling of the border issue, in accordance with the conflict-theory model, has not been completed.

turn of the simulation as shown in 2.14.

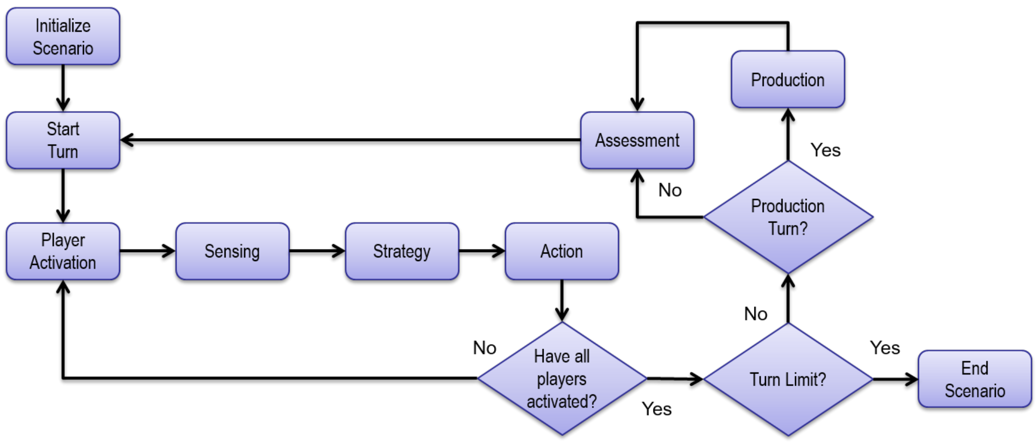

Figure 2.14: Enhanced RealLand Simulation Process

The scenario is initialized under a variety of setup parameters, such as the number of players and size of geography. Once configured, the scenario can be run. A turn begins as players are activated in an ordered fashion. During the sensing and strategy phases, the players check the environment for internal and external considerations and formulate a strategy. During the action phase, players implement their strategy by forming alliances, re-positioning forces, engaging in trades, and executing military operations. In the case of trade deals, they are given an opportunity to continue seeking trades and alliances until they are either rejected by all potential partners or they find one that will entertain their proposals. If it is a production turn, players receive their previous orders and plan for their next production cycle.[23] The assessment phase determines whether or not a player stays in office and adjudicates any internal instability caused by low validators' satisfaction.[24] Once all players are activated, the turn comes to a close. The turn cycle repeats until the scenario limit is reached.

[23]The lag has not yet been implemented. Currently players make and receive their orders simultaneously.

[24]This has been implemented. However the assessment phase should also address the consequences of removal from office and internal security which it currently does not.

Initialize Scenario A scenario begins at Turn 0. Players are given at least one production center in a city usually with a surrounding set of hexes. However, forces have not been allocated. To determine force structure, Enhanced RealLand uses a player's national power based upon the available elements of area, production factors, oil, wheat, and cities. The concept is to generate a set of forces relative to a player's power so as to keep their power ranking. This ensures weak states are not given a powerful military and vice versa. However, a state's national character has an influence. States that care less about security will have less standing military forces. Once the combat factors are determined, a state must develop its order of battle. The initial order of battle assigned is based upon a set of rules to provide a reasonable lay-down for the country addressing the weakest to the most powerful. Figure 2.15 illustrates a three player world. The cells are painted to indicate player territory as opposed to terrain.

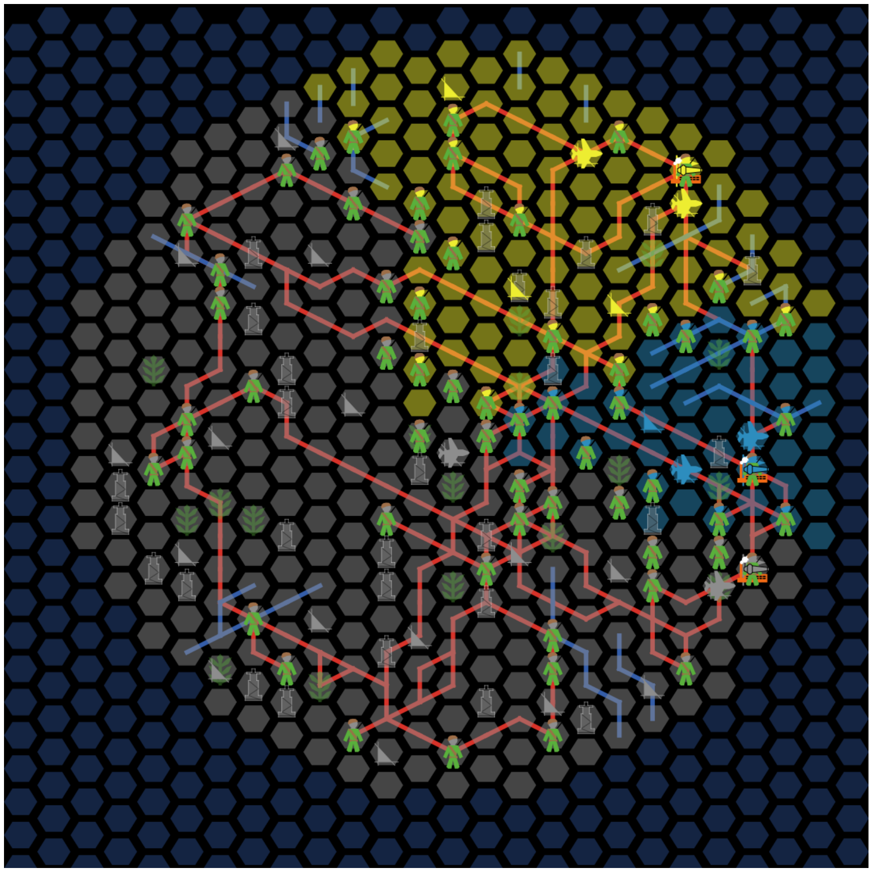

Figure 2.15: Generic Unit Laydown

When players take their turns, they can reallocate their forces as they see fit subject to movement constraints defined below in the action phase.

Player Activation During each turn, Enhanced RealLand players proceed in an ordered sequential fashion. This is a common wargaming technique where no player may take another turn until all the other players have had a turn. This differs slightly from common ABM activation where an agent may have two moves before another agent. In that case, the agent may go last on one turn and first on the next activation phase. There is one nuance to sequential activation within the action phase. To account for simultaneity of actions which the turn represents, the defenders of kinetic actions are given the opportunity to react. This mitigates the favoritism shown to the aggressor by assuming some indications and warnings would be available, and the defender would have an opportunity to marshal additional forces. For convenience, the ordered list is spatially based beginning in the lower left of the environment.[25]

Sensing Phase. The objective of this phase is to identify issues that could warrant changes in strategy or an altogether new strategy. Players perceive the realities within the international system and generate issues. Issues take the form of a quadlet defined by *who is involved*, *what's happening*, *how bad is it*, and *how long has it been going on*. Players will:

- Update their national power and determine who is rising and failing in power. Determine delta from previous turn. An issue is generated for all power differentials.
- Check if wheat or oil are not at sufficient levels. Determine how long this has been a problem. Any shortages will generate an issue.
- Ascertain if neighboring players have increased their forces on the border. Determine if this is a trend. Generate an issue for any border increases.
- Assess which nations have force projection capabilities (i.e. fighters, bombers, and armor) and if they have resource shortages. All states with force projection capabilities will generate an issue.
- Assess the situation of any defensive wars in which the player is involved and determine its status. All alliance requests will generate an issue.

An advantage of this desk clearing approach is that issues are stored by turn so players have the option of reviewing issue history as needed. A player that attacked another player's

[25]When forces are joined in joint kinetic operations with other players, they pass on their position within the turn structure and wait until the turn of the last player within the alliance to activate. This ensures alliance countries operate in a bloc format with a picture based upon the same ground truth. The delayed activation for some agents is justified with the challenge of integrating military operations. Military operations will not be planned or adjudicated until all the countries within an alliance block have had their turn. The intent behind these rules is to effectively manage simultaneity in a sequential manner. However, this has not yet been fully implemented. A unit can currently be attacked twice before they receive a chance to respond.

country in the past did so because of strategic calculations and may do so again if conditions change.

Strategy Phase. A player's strategy is the set of actions that they wish to perform during the turn. A strategy is a set of actions in a quadlet including *what am I doing, to whom am I doing it, what do I want, and what will I leverage to get it.* Players will process each issue in accordance with the conflict-theory model of strategic decision-making show in Figure 1.5.

Resource Shortage. Resource shortages are a strategic issue for the player as an element of national power. If the current strategy already addresses resource shortfall per position uncertainty or some other yet to be implemented issue, the player will assume the matter closed, and move on to the next issue. Otherwise, the player will assess the risk of doing nothing. In this case, the risk is dependent upon the magnitude of the shortage and the player's risk tolerance. If the shortage is a significant proportion of the the total production factors or cities, the player will likely consider the risk of inactivity serious. Otherwise, the issue will be marked as *unconflicted adherence* as the player takes no new actions with respect to the issue.

Advancing to the next question within the conflict-theory model, players will consider the easy options. If a player can trade for at least some of the resource or if there is an extremely weak neighbor to conquer, the player will satisfice and move onto the next issue. This is classified as *unconflicted change.* However, as the duration of the shortage grows, the stress will rise and force the issue to the next stage. Here the player looks for hope by searching for a feasible course of action. If the player is weaker than its neighbors and there are no potential trading partners, the player will exhibit *defensive avoidance* and do nothing.

If options are available, the player will determine if they have time to find a better solution. Each production turn that passes with a resource shortage is a significant loss to the player. If this is combined with consistent losses in national power, the player will believe that it has no time to respond. It will immediately engage in a dangerous conflict. This issue will be marked as *hypervigilance*.

If time is available, a *vigilant* player will evaluate their ledger of trades, potentially ending or renegotiating poor or outdated trading agreements. If a shortage remains, the player will seek to build an offensive coalition against a neighboring to better the odds.

Defensive War. A defensive war is when a player must defend themselves from another player. An example of a defensive war could be [Defensive War, Player B, defend/reclaim territory, all forces] where players are using all there military strength to repel the attackers from their territory and reclaim lost territory. Similar to resource shortage, a defensive war issue is implemented in accordance with the conflict-theory model.

Upon receiving a defensive war issue, a player will identify all players in the attacking coalition and all players in the defending coalition. This ensures that players provide a holistic defense in execution. If the defending alliance has more forces than the attacking alliance and national power did not decrease since last turn, the player will be adverse to risky ground and air engagements.

If this is not the case, the player will seek a defensive alliance with other players adjacent to the attacking coalition. Otherwise, the player will evaluate its industrial base against the opponent. If the player determines that its industrial base is superior, it will have hope for a better solution. The question of time availability is directly related to the proximity of the enemy to the target's capital city. If the enemies are at the gate, the player will be pressured into riskier attacks in an attempt to thwart the enemy. If sufficient distance is present, the player will seek to hold and potentially advance on enemy strategic terrain.

Action Phase. The action phase enacts the strategy; however, it is the only phase where other players are given the chance to respond. The action phase adjudicates trade and alliances, unit movement, and wars.

Trade in Enhanced RealLand is a simple market system. Players form a market of buyers and sellers for each resource pair. A player submits an action [Trade, all players, 2 oil, 4 wheat]. The player formulates its asking price that is a random integer of what it is willing to offer. It then approaches each player in the pool that has its own bidding price (a random integer of what that player is willing to trade) that is greater than its asking price. The bidding price is a random integer of what the other player is willing to offer. Simply put, each player presents a trading price that is bounded by its most unfavorable, but still acceptable trade. If the players find an acceptable price, a trade will be added to the global trade ledger. Several trades may occur until the player either runs out of surplus supply to trade, no one is interested in trading, or it meets its objective amount. If there are no surplus resources for any player, there will be no trade for that resource. A player will never make a trade that will result in a worse situation.

Currently, offensive and defensive alliances within RealLand are ad hoc pleas for support. Players ask either their neighbors or the neighbors of the opposing players. Accepting an alliance is done during each player's turn. If multiple alliance requests are made, the players will select the one with the best force ratio.

War actions usually involve the movement of military units. Players may move units subject to the number of hexes that the unit can traverse given their range. Table A.1 provides proposed terrain constraints that have yet to be implemented. Units move on the shortest path towards an objective location unless they encounter obstacles. Ground units will stop upon reaching an opposing unit's zone of control, or if they can find no suitable location to proceed. Tactical movement takes place as units attempt to achieve required force ratios.

Operational movement occurs as units traverse from one part of their country to another. In general, the player will attempt to secure its cities, borders, airbases, and position reactionary forces as needed across the country.[26]

To keep things relatively simple in Enhanced RealLand, militarily operations have been simplified into three core missions: air superiority, strategic strikes, and ground combat. While players dynamically plan to go to war and may interfere with the prosecution by prompting riskier attacks, military operations follow some basic logic.

1. Perform DCAP sweeping missions as part of a SAC mission. This is where the player's fighters attempt to reach the targeted hex. In so doing, they will fly through the DCAP and air defense zones of other INT, FTR, or air defense units which will scramble to intercept. If the defense exceeds the combat factors on the fighters, the SAC will not launch for the strike. Air superiority is adjudicated based upon Table A.2. SAC targeting is optimized to achieve the most impact where air superiority is present. SAC will only be lost by attacking an airbase directly.

2. Perform all SAC strikes. Assuming the air has been cleared of defenses, the bombers will conduct the strike. Air power will default to destroying ground forces unless it can reach the opponents airbases and production centers. The strike is adjudicated by Table A.3.

3. Ground combat surveys the forces on the battle field and pits the adjacent forces against each other if the attackers have a ratio greater than 3:1. Each ground engagement is adjudicated by Table A.4.

Production Phase During the production phase, each player makes and receives its order placed during the last cycle. Any military units will appear at production centers or

[26]The strategic movement of forces has not been implemented. I would envision the only non-threatening way to traverse to a neighbors country is on either railroad or military air transport. Before they can peaceably traverse another country's air or ground, they must ask permission. If the destination is in another country, units will seek to move first to a rail-line to await a railroad unit. If a military air transport is near, they will reserve their spot and move to the closest military air transport unit.

the closest airbase from a center in the case of air units. Those units will be available to respond to issues in the player's turn.

Players use their past history since the last production turn as the basis for purchasing new orders. A production order is simply what and how much the player wants to buy. For production purposes only, issues are tracked by the level of stress induced on the player. More stressful issues are more salient in driving production orders. A player struggling with border security will build more forces. Another player unable to feed its people may try to develop more wheat. Issue salience is scaled according to the conflict-theory model starting with 0 for unconflicted adherence (though hypervigilance will have more salience than vigilance).

$$PF_i = \frac{O_i S_i}{\sum_{j=1}^{n} O_j S_j} PF_t \tag{2.13}$$

Where O_i is the occurrences and S_i is the salience of issue i since the last production turn. n is the total number of issues and PF_t is the total production at time t. Weak countries with only one or two production factors will have to prioritize across the issues. Now that a player has a sense of what issues to spend on, it has to decide what to purchase. In the case of wheat or oil shortages, the player may take a chance on developing new oil fields or agricultural centers. In the case of war, military forces will be developed. In the case of economic dissatisfaction, players will invest in the economy and resource development. Any unused production factors are saved for the next production turn. In the case of military unit selection, Enhanced RealLand assumes that every player follows the path from internal security to border security to force projection.

Assessment Phase While this phase will eventually adjudicate internal dynamics, it currently serves to adjust and reset values before advancing the turn.

2.2.3 Implementation

Enhanced RealLand is implemented in NetLogo 6.0.2, 64 bit version. While the model is agnostic to the dimensions of the simulated geography, the size of the grid should have a surface area of approximately 7,000 hexes for 18 players (390 hexes per player). This heuristic was determined through experience in the wargaming tradition to focus on force employment at the operational level of war. If the simulation is too small for the number of players, the operational constraints begin to degrade. However, performance issues exist when the number of players exceeds 18 and the hexes exceed 7,000. However, NetLogo's ease of use as a prototyping tool met the needs of this research.

2.2.4 Verification

Like most unique agent-based models, Enhanced RealLand is verified through code walk-throughs, limited parameter sweeps, and detailed examination of each event within the simulation (Cioffi-Revilla, 2014). This includes the setup of the environment and the agent interactions over a run of the model. The first verification step within Enhanced Real-Land is setting the random seed. This feature allows for the reproduction and isolation of any errors or bugs within the setup and execution of the model. The second step involves leveraging object-oriented programming methods and best coding practices to make the code as stable and readable as possible. This includes the isolated testing of each feature during initial development. NetLogo has a limited debugging capability when compared to more robust development environments; however, it is sufficient for tracing most bugs. The final step combines limited parameter sweeps and detailed examinations of model behavior to check for logic or coding errors. For verification purposes, 10 countries are initialized. Any more are deemed too costly in runtime and any less insufficient to get the breadth of interactions. The following are the verification tests performed:

1. No resources (100 runs for 100 iterations with 10 players): With no resources present within the system, computer players will attack their weakest neighbor. Depending upon their decisional conflict, they may request an offensive alliance with another

player bordering the target. Likewise, the targeted player may request a defensive alliance with another player bordering the attacker. Currently, there is no ability to request and receive forces from non-neighboring countries, but that is near completion. This was the primary test to debug alliances and combat. Overall, the model performs as expected where players kept engaging neighbors until they could no longer achieve sufficient force ratios to engage in combat. Without production capabilities, players have no ability to replenish losses. Players always allocate forces to defensive wars first by design. Ground units on strategic terrain tend to provide a barrier to advancement. A feature that is noticeably missing from the defensive war issue is appeasement. This is the ability to essentially trade resources for a non-aggression pact. Similarly, this is tied to the ability to trade resources and production factors to spur support for defensive or offensive alliances. Enhanced RealLand has placeholders for these features.

2. Surplus resources and no production (single run for 10 iterations with 10 players): With each player having ample resources, there is limited activity within the model. Only non-issue movement takes place. A minor coding problem remains with non-issue movement. Movement of air defense units is not yet implemented.

3. Surplus resources with production every turn (10 runs for 10 iterations with 10 players): Each player will accrue additional combat units as expected placing them in production cities and then distributing them appropriately across the country with a tendency to be on roads near borders. The production itself appears to be working as designed as players first seek sufficient force levels for internal defense and border security. Players will seek median force for reactionary forces (primarily mechanized infantry). Once achieved they will build more sophisticated weaponry and seek to develop their industrial base in order to do so. As players advance their industrial base, oil shortages occur which lead to trade or conflict.[27]

[27]This is an area for future modeling and verification. I have intentionally not included runs where production would be a significant factor on operational play.

4. Shortage of resources with production every 12 turns (100 runs for 100 iterations with 10 players). This is considered a standard run of the model. The trade model works as expected in exchanging wheat and oil. The model suffers from a lack of ability to *purchase* wheat or oil with production factors. This feature has yet to be implemented. Additionally, giving the players the ability to gamble on resource development every production turn seems unrealistic. Additional terrain types, seasonality, and climate have begun to be incorporated, but remain untested.

5. Other issues such as border security, hungry players, position uncertainty (100 runs for 100 iterations with 10 players): Other issues currently remain in the verification stage and consequently will not be used for validation or analysis until completed. Each additional issue provides greater capacity for replicating strategic decision-making.[28]

2.2.5 Validation

The structural validity of the model was discussed at great length in the model description and theoretical framework sections. Behavioral validity is the main concern here. Under the wargaming approach to computational IR, the most important validation concern is the simulation of and approximation to the strategic decision-maker. The stochastic output will be the primary focus for discussion in the next section. Here, the concern is how the computer player functions within the Enhanced RealLand wargame. To do this, I provide a limited walk-through.

The case to be examined is a multi-polar system initialized randomly with 4 players shown in Figure 2.16 with the national power and combat factors provided. In this situation, there exists a strong country bordering two relatively weak countries and one moderately powerful country on a single continent. Country A is three to seven times more powerful than the others. However, the force ratio is far closer with Country D having some force projection capability. As initialized, wheat and oil are in extremely short supply increasing decisional

[28]The details on additional issues are discussed in the Appendix.

conflict. Only two countries have wheat and oil: Country A and Country D. Country B and C only have oil, but only Country B has a shortage. Country B is the weakest of the four countries. Country D only borders Country A. Inspection suggests that Country A is going to engage Country B for oil for a swift, low risk victory. Country D is going to wait it out. Country B and Country C will have defensive avoidance as there is no solution to their wheat resource shortages. This is essentially what occurs during the first iteration.

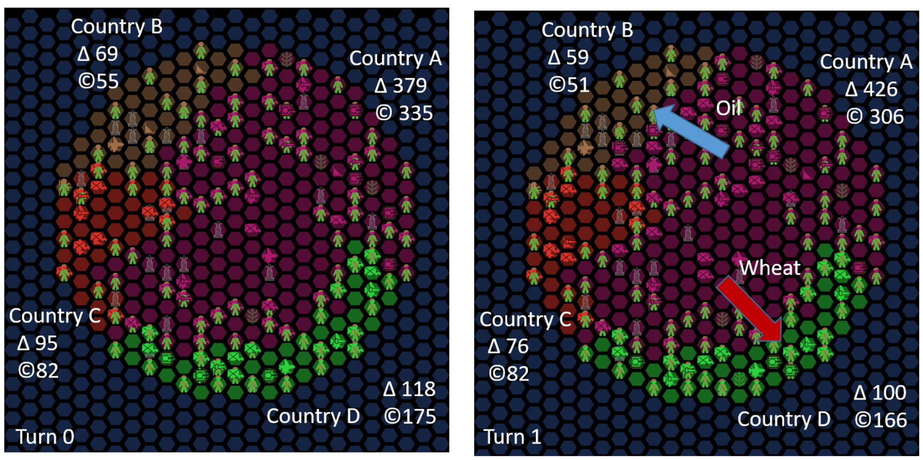

Figure 2.16: Enhanced ReaLLand Illustration

At the beginning of its first turn, the Country A player discerns its shortage in both wheat and oil. An issue is created for each. Evaluating the oil shortage, the player determines that action must be taken as the gap between supply and demand is beyond its tolerance level. With the increase in decisional conflict, the player processes more information examining potential trading partners and finds none available. The player turns to examining its military options and determines that its force ratio with Country B exceeds the engagement ratio for an overrun (meaning aggressive action should lead to quick decisive results). The player marks the issue as *unconflicted change* and submits an action allocating as much as ten times the force structure of Country B to the conflict.

The next issue before Country A is wheat shortage. The process follows the same logic just described except the target is Country D. Country D is the only neighboring player with wheat resources. However, the force ratio is not so one-sided. Finding no easy options for war or trade, the decisional conflict increases to the next stage. The player further surveys all neighbors for potential conflict and all countries for potential trade. Finding itself a dominant country in the region, the player advances to examining the question of time for a solution. As the effect of the shortage has not been realized during a production turn and Country A is not declining in power relative to the other states, the player will exhibit *vigilance* in addressing the issue. Consequently, the player weighs the cost of engaging Country D and determines it doesn't have significant strength to engage it. The issue salience is flagged as one of *vigilance* and no actions are submitted. The player concludes its turn after engaging in ground combat and moving additional forces.

During the war adjudication, the ground forces advance on the oil fields. Ground engagements are preceded by fighter sweeps where Country A's air units engage with Country B's to clear a path for strategic bombers. The bombing and the air campaign is only somewhat successful leading to the attrition of some enemy air defenses and one ground combat factor. Sufficient forces have not advanced to the conflict area to achieve a 3-1 ratio so ground combat does not take place. Following Country A, each country takes its turn deciding not to take military action due to either hopelessness or prudence.

By briefly outlining a player's logic within this scenario, the course of action by Country A is certainly a feasible one given the defined information processing and possible options. This is the point. Country A has demonstrated a course of action that a human player could take to advance their national power. It is certainly not the only action or potentially not even close to the optimal one. Through stochastic simulation and parameter sweeps, possibilities under different conditions will emerge. Additionally, the model can be run for far longer than any social simulation. This kind of analysis is a key contribution of computational IR and will be discussed in the next section.

The decisive empirical validation test would be to engage in a set of social simulations which is beyond the scope of this effort.

2.2.6 Analysis

Now that Enhanced RealLand has been verified and some face validity has been achieved in representing a feasible course of action, the model can be executed more richly. The focus is on understanding the outputs of the model through the lens of national power. National power is a normalized index based upon the elements of national power including area, resources (wheat and oil), production factors, population (cities), and military strength. This section is intended to analyze the model output by addressing the following questions.

1. What is the impact of chance on a player's national power? These sets of runs explore the impact from building the environment with a common random seed, but changing it at run-time. The players have the same initial conditions each run. Are their actions always the same? Does it make a difference?

2. What is the impact of global run-time parameters on the model results? These runs are performed similar to the previous question.

3. What is the impact of exploring different initial conditions? These runs are executed with a unique random seed. What is the range of behaviors present within the model?

Randomness At run-time, there are a few stochastic processes that could have an impact on the outcome. The first is the chance advancement beyond the decisional conflict state of unconflicted change. The concept is that anxiety over any change will increase over time which will have the effect of making any change conflicted. This chance could have a strategic impact on the player by forcing them into either defensive avoidance, hypervigilance or vigilance.

The rest of the variance is associated with the success of harvesting new resources, favorable trade deals, combat adjudication, and unit movement. This section first examines the impact of chance on national power though a 100 reps of 100 iterations from the same initial conditions shown in Figure 2.17.

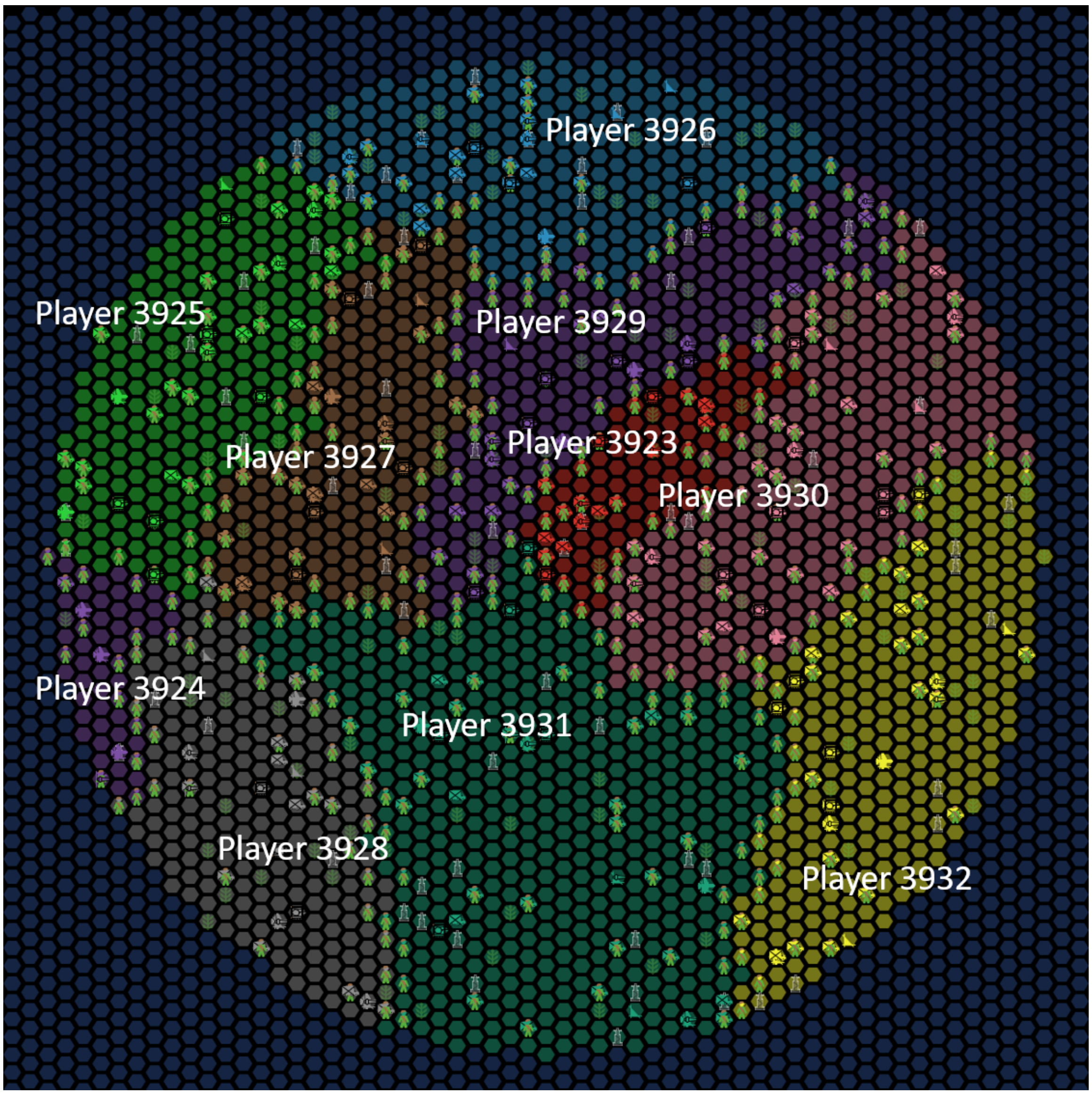

Figure 2.17: Enhanced RealLand Starting Condition for Stochastic Analysis

In this scenario, there is no dominant power. Player 3931 has the greatest relative national power largely due its size compared to the others, but player 3930 has more production factors. The world itself has a general wheat shortage and oil surplus though some players may have shortages.

Figure 2.18 shows the distribution of national power at Time 100. The star shows the fixed position of national power and each of its elements at Turn 0. As shown, there are are some low probability outcomes, such as Player 3923 surviving the conflict.

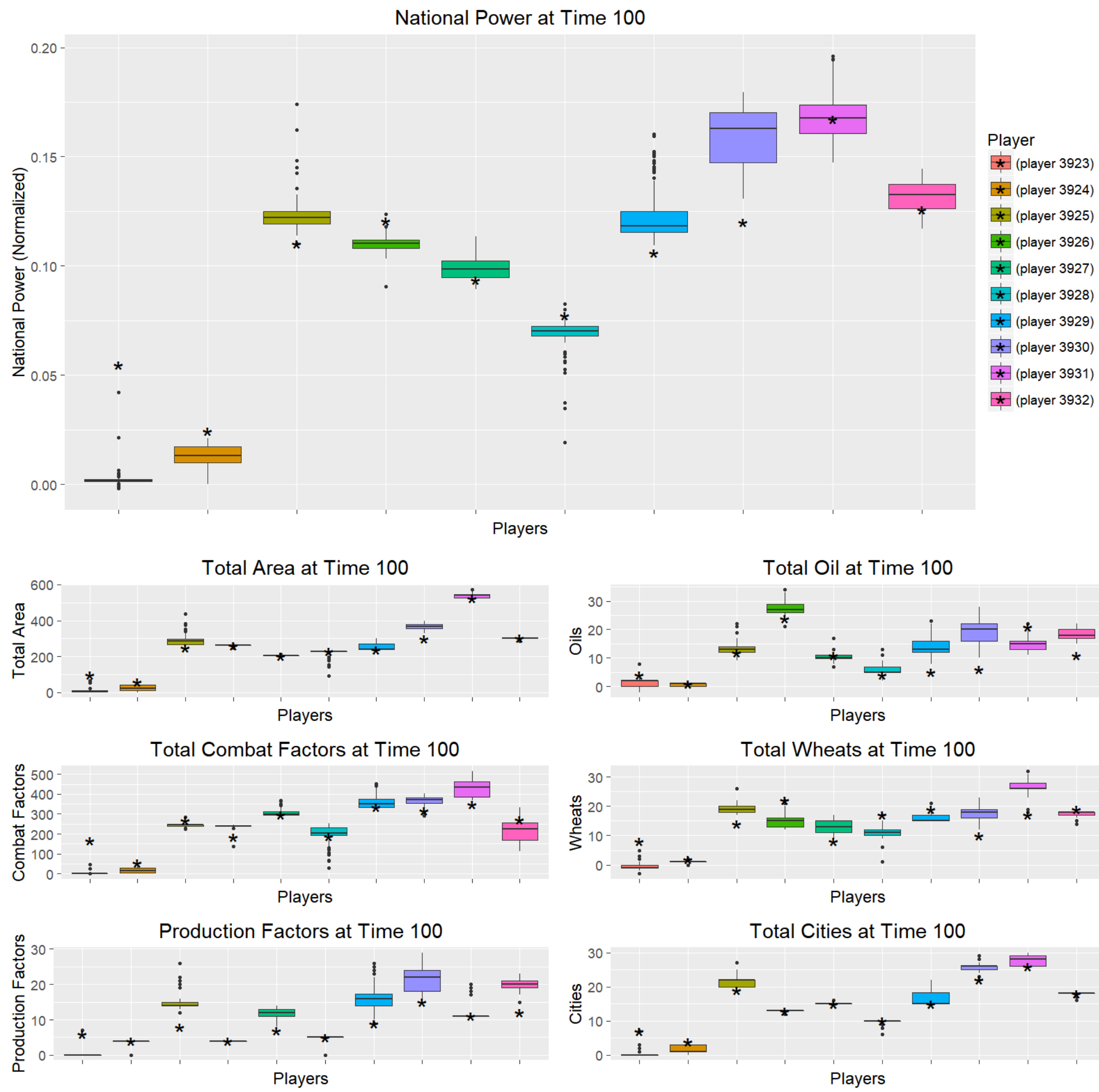

Figure 2.18: Enhanced RealLand Stochastic Analysis Results (100 runs for 100 iterations)

The results show that the stochastic elements within the model had an effect on the way ground combat played out but not necessarily a strategic one that significantly altered the course of the run. Player 3928 is usually conquered by player 3930. Country size across the turns is shown in Figure 2.19. Player 3923 began to lose territory at the onset increasing over time until it had very little area left.

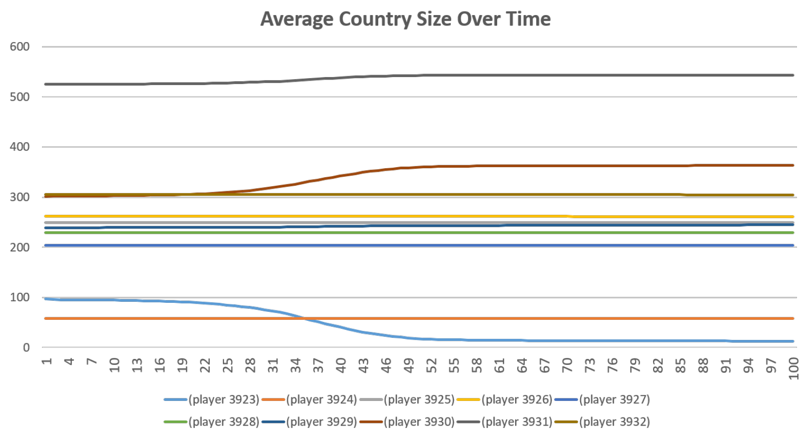

Figure 2.19: Enhanced RealLand Stochastic Analysis Results by Country Size (100 runs for 100 iterations

Given there is a detailed log of player actions, we can begin to understand the chain of events that led an increase in power. A single iteration can be traced and understood. The following is an example of a detailed accounting of the course of events.

Turn 1

- Player 3928 has a single issue which is a shortage of 1 oil with a risk tolerance of .75, the player experiences *unconflicted adherence* and takes no additional actions.

- Player 3924 has both an oil and wheat shortage (a hungry player) leading to a state of *vigilance* on both issues. As one of the weakest states, it declines to attack its weakest, but still stronger, neighbor (player 3928).

- Player 3931 has a shortage of wheat but is able to trade. Keep in mind the chance for decisional conflict to increase when a player changes its course of action. Any unconflicted change may lead to additional anxiety. It trades for 17 wheat in exchange for 7 oil across five different players.

- Player 3930 is a hungry player. It elects to attack player 3923 for both oil and wheat resources requesting an offensive alliance with player 3931. They begin the offensive this turn primarily with an air campaign as its ground units have not marshalled in sufficient numbers along the border to overcome the defenders force ratio benefits within mountainous terrain. The strategic bombing of an airbase catches some planes on the ground. Overall, it was a fairly even exchange in the air campaign as the player was engaging in 1-1 air battles.

- Player 3927 has a wheat shortage but is able to trade. They cumulatively trade 3 oil for 7 wheat with two players.
- Player 3923 has a oil shortage, but is able to trade. However, they have a defensive war issue against player 3930 and request a defensive alliance with player 3931. Player 3931 will have to choose whom to support.[29]
- Player 3929 has no resource issues.
- Player 3925 has a wheat shortage issue of 5 wheat. Due to chance, its decisional conflict has increased and they have elected to attack player 3924. A 3-1 ground combat ended in an exchange and a bombing run on an enemy airbase was successful.
- Player 3932 has no resource issues.
- Player 3926 has no resource issues.

Changes during Turn 2

- Player 3924 (target) finds itself in a defensive war against player 3925 (initiator). It views the situation hopeless.[30]
- Player 3931 receives two requests for an alliance. It declines a defensive alliance with player 3923. However, the player joins in an offensive alliance with player 3930 against

[29] In the base runs, a player will always select the one defensive or offensive alliance with the greatest force ratio to join.

[30] This is where the player should attempt appeasement before this point or potentially surrender to be implemented at a future date. Instead they continue to fight a conservative defense action. However, it has no ground units adjacent to the enemy this turn.

player 3923. This alliance request offers the best combined force ratio. However, the player declines to make any attacks due to the needed ground force ratio.[31]

- Player 3930 conducts a major offensive with air attacks. No ground attacks are conducted though the force ratios improve. An enemy airbase is destroyed.
- Player 3923 (target) is being attacked by player 3930 (initiator) and 3931 (ally) and postures for defense. It believes it is a hopeless cause.
- Player 3929 has no issues
- Player 3925 has a wheat shortage and is able to trade 4 oil for one wheat.
- Player 3932 has no issues.
- Player 3926 has no issues.

Hopefully, the point is taken that detailed results can be explored and understood. For this particular iteration, the war continues until player 3923 is completely defeated. The next major engagement is against player 3924 as player 3925 begins an attack due to a wheat shortage. Additionally, player 3927 seeks wheat from player 3928. The world at Turn 100 is shown in Figure 2.20.[32]

[31] The fact that the player didn't fly any sorties is a current model limitation in how allies allocate aircraft in a defensive war.

[32] Enhanced RealLand will print out the complete logging of events if desired. This is used to convey the story of the run when combined with the map.

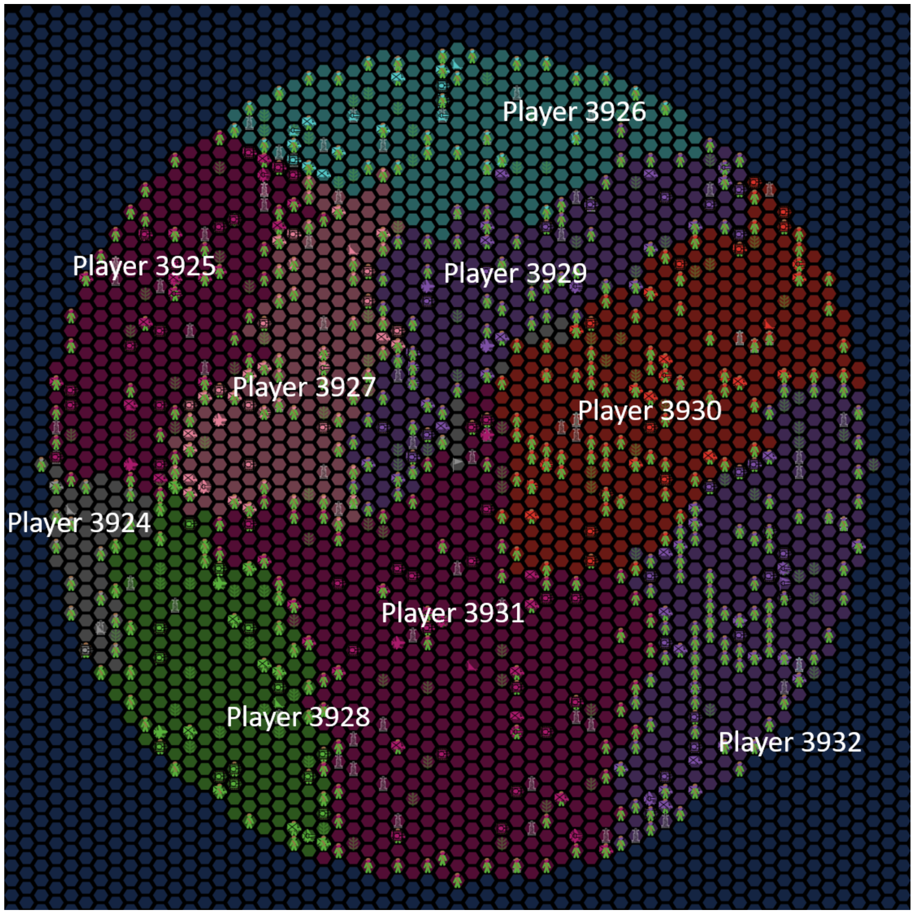

Figure 2.20: Enhanced RealLand Ending Condition for Stochastic Analysis

Parameters The run-time parameters used above were considered at a default setting within Enhanced RealLand. A player will engage in a war if the force ratio with the target exceeds the engagement ratio. Combat units initiate an engagement when they are able to exceed the ground and air combat ratios.

The default parameters assume hypervigilant players are willing to accept more risk conducting attacks at a 1-1 force ratio. Force allocation is also a parameter. Each attack or defense requires a committed force structure. How much should a player commit to an engagement? Does potentially overwhelming force lead to quicker outcomes or mixed result?

The force allocation and the defending terrain are likely related. To show the impact of run-time parameters, 200 additional runs were completed. One set of hundred used a force allocation of 1-1. The other set used a 6-1 ratio for force allocation.

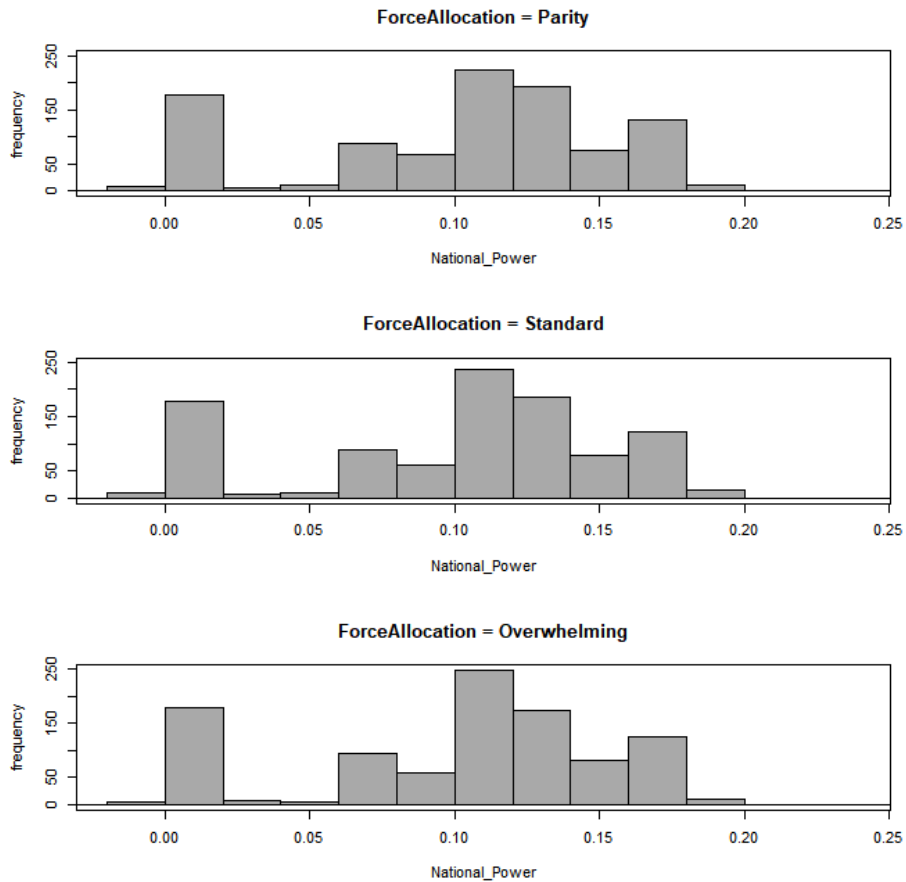

Figure 2.21: Enhanced RealLand Parametric Analysis

Interestingly, the force allocation ratio seems not to have played a significant factor at least within the present international system. It appears that the structure of the international system has far more impact than any run-time parameter.

Exploring Different Initial Conditions With Enhanced RealLand, it is possible to explore nearly unlimited what-if situations where the structure of the international system is altered. In this case, the artificial worlds are initialized with the demand for wheat and oil roughly equal to supply. Players have equal number of production factors and the technology level is constant. The terrain is mostly clear.

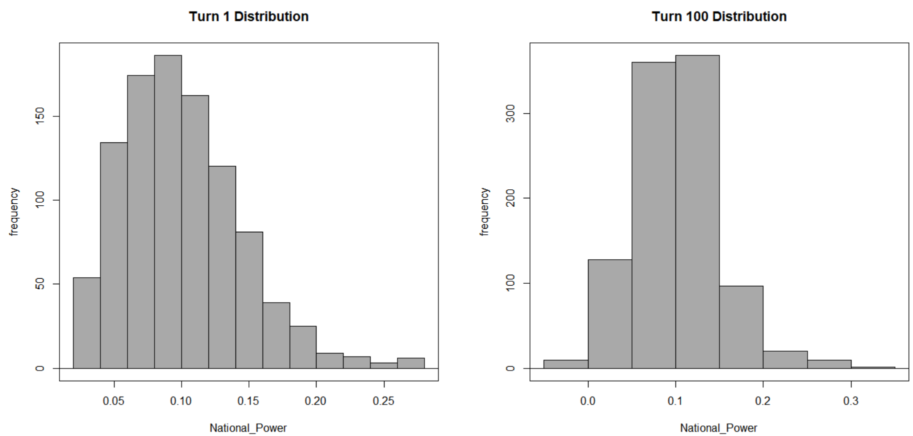

Figure 2.22: Enhanced RealLand Change in National Power

Figure 2.22 illustrates the change in the overall national power distribution from Turn 0 to Turn 100. The starting national power distribution resembles a log-normal distribution which was unplanned. By Turn 100, the power distribution across the 100 runs appears closer to a normal distribution. While a few states gain power within the run, there appears to be a balancing effect where states tend to converge towards similar power levels over time.

Chapter 3: Results: Answering the RQs

The MDIVVA process documented in the previous chapter focused on the verification, validation, and analysis of Basic and Enhanced RealLand. *The purpose of this chapter is to answer the research questions declared in Chapter 1.*

3.1 RQ1: A Wargaming Approach

Can a wargaming approach to computational IR be used for conducting advanced IR research, where verisimilitude in detail enhances rather than detracts from the epistemological value?

As outlined in the previous chapter, Enhanced RealLand is a proof of principle of a wargaming approach to computational IR. It is the main result to be evaluated in this section as my instantiation of a wargaming approach to computational IR. The focus is on understanding the outputs of the model through the lens of national power. National power is a normalized index based upon the elements of national power including area, resources (wheat and oil), production factors, population (cities), and military strength.

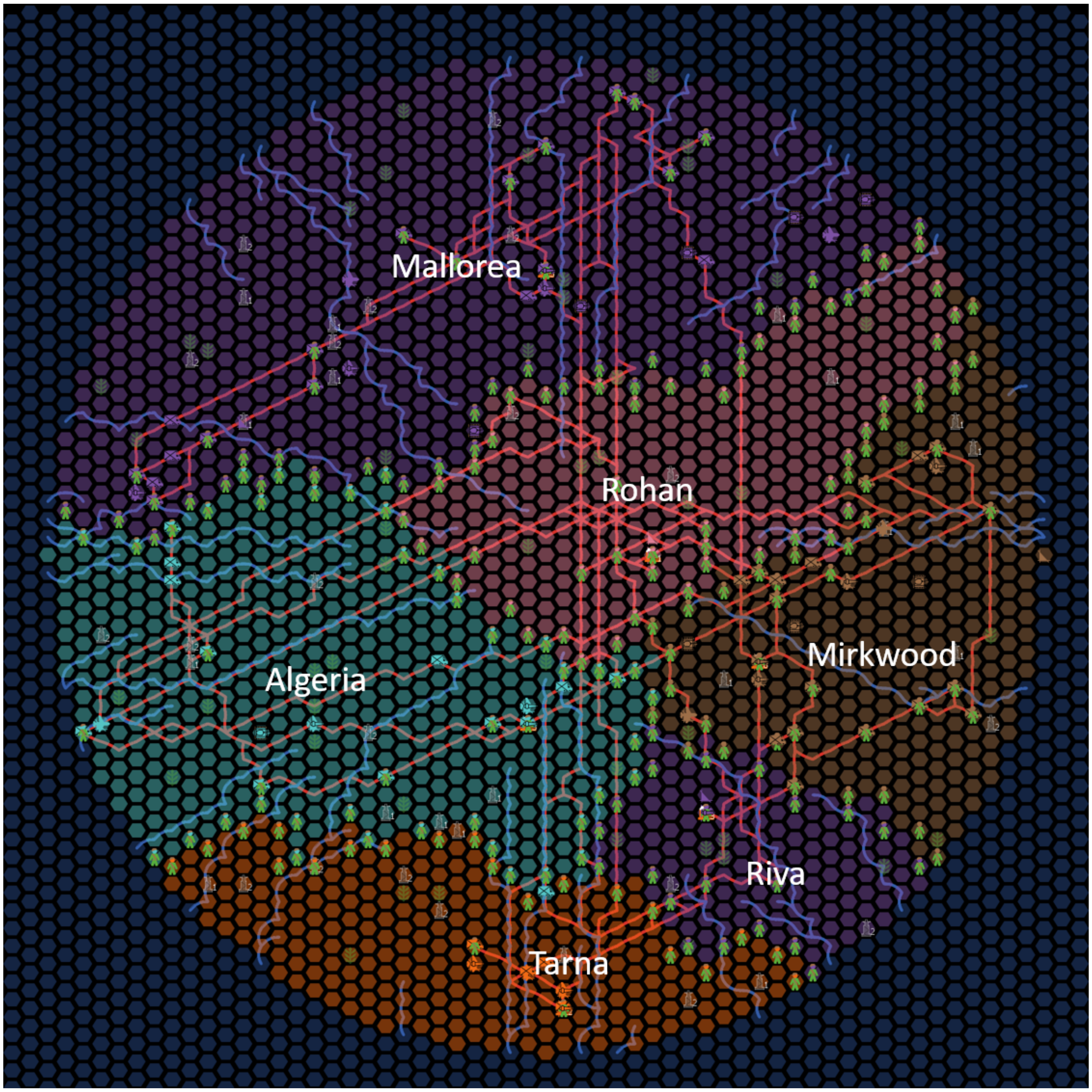

Figure 3.1: Scenario 6 World Map

To illustrate the value of verisimilitude in detail, I will describe a scenario (S6) as shown in Figure 3.1. There are six simulated nation-states existing on a large island with randomly placed terrain and natural resources. Each player begins with contiguous terrain, at least one production center, and an order of battle. Each country possesses certain forces, cities (population), production factors, resources (wheat and oil), and size indicating its power.

S6 is a multi-polar world, meaning no country has a clear dominance. The polarity analysis yields three stronger powers (70% of total power) and three weaker powers (30% of total power). In order to understand the game history of S6, the players need to be explained in additional detail.

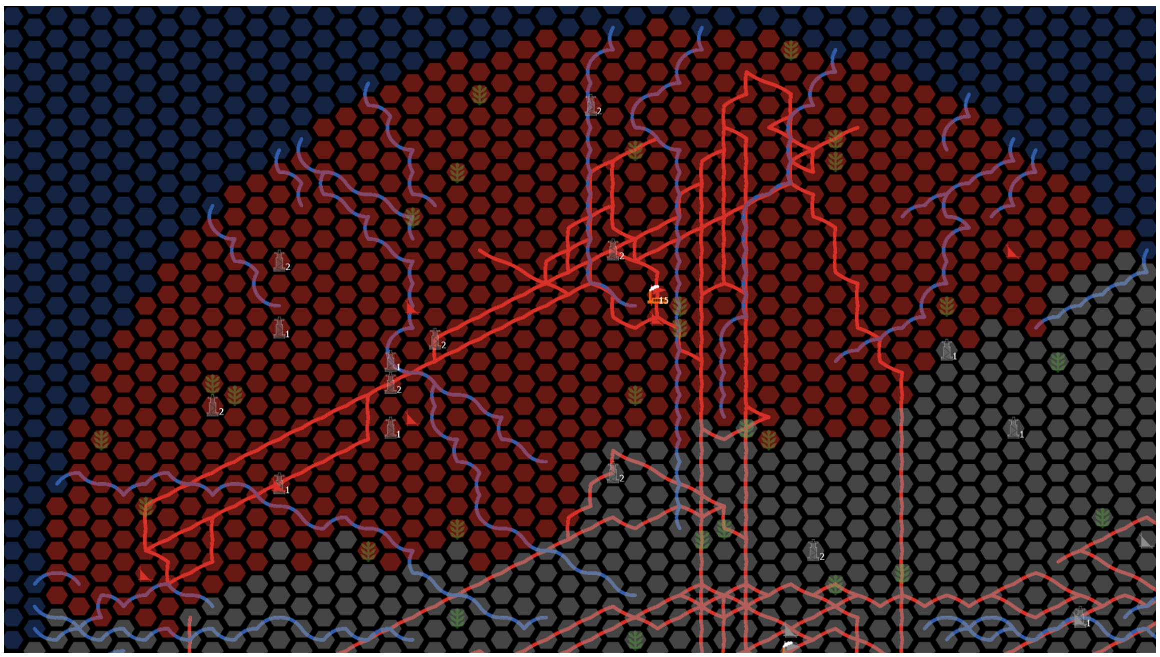

Figure 3.2: Mallorea

Mallorea. Player 3815 controls the most powerful country on the island on any measure. Mallorea is by far the largest country consuming almost a third of the land mass. It has a surplus of both wheat and oil. Player 3815 possesses a significant military with larger numbers of SAC, FTR, and ARM. Mallorea borders two states to the south (Algeria and Rohan).

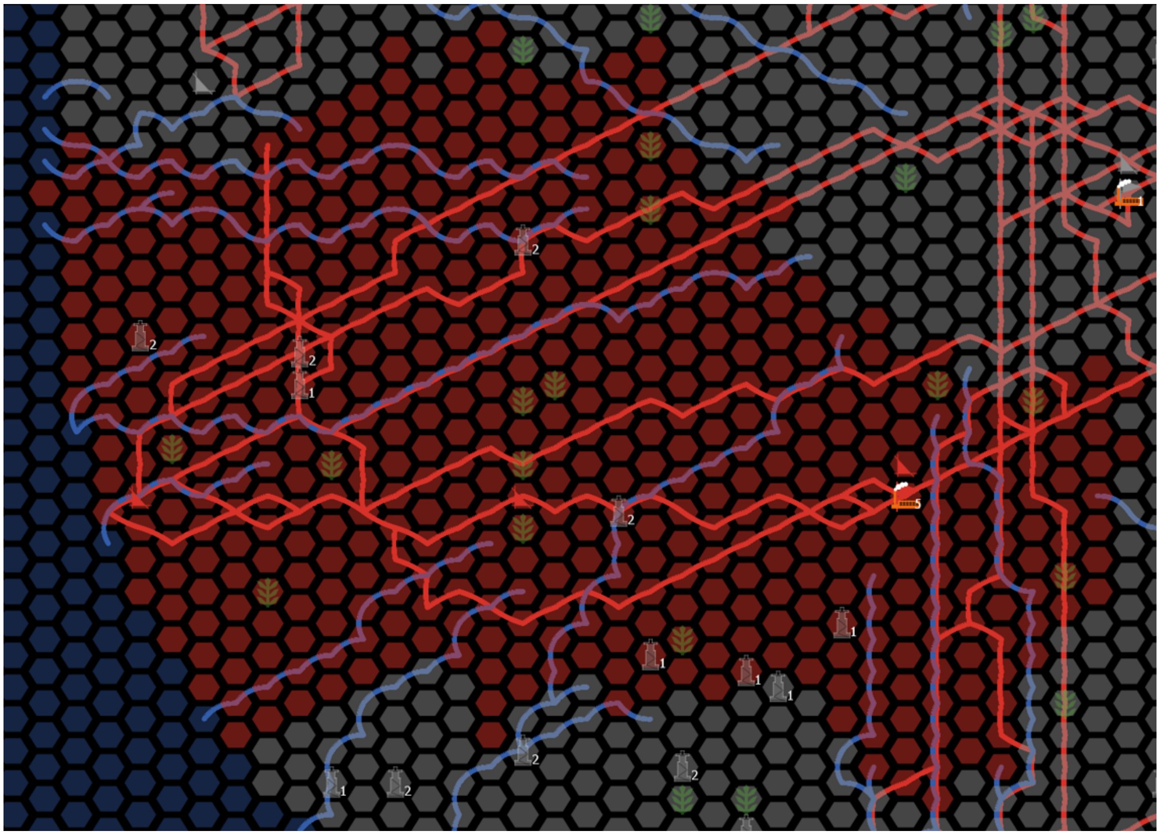

Figure 3.3: Algeria

Algeria. Player 3816 controls a surplus of wheat and oil although Algeria's production factors are low. Algeria is the next most powerful state due to its large size. Algeria shares a border with all other countries.

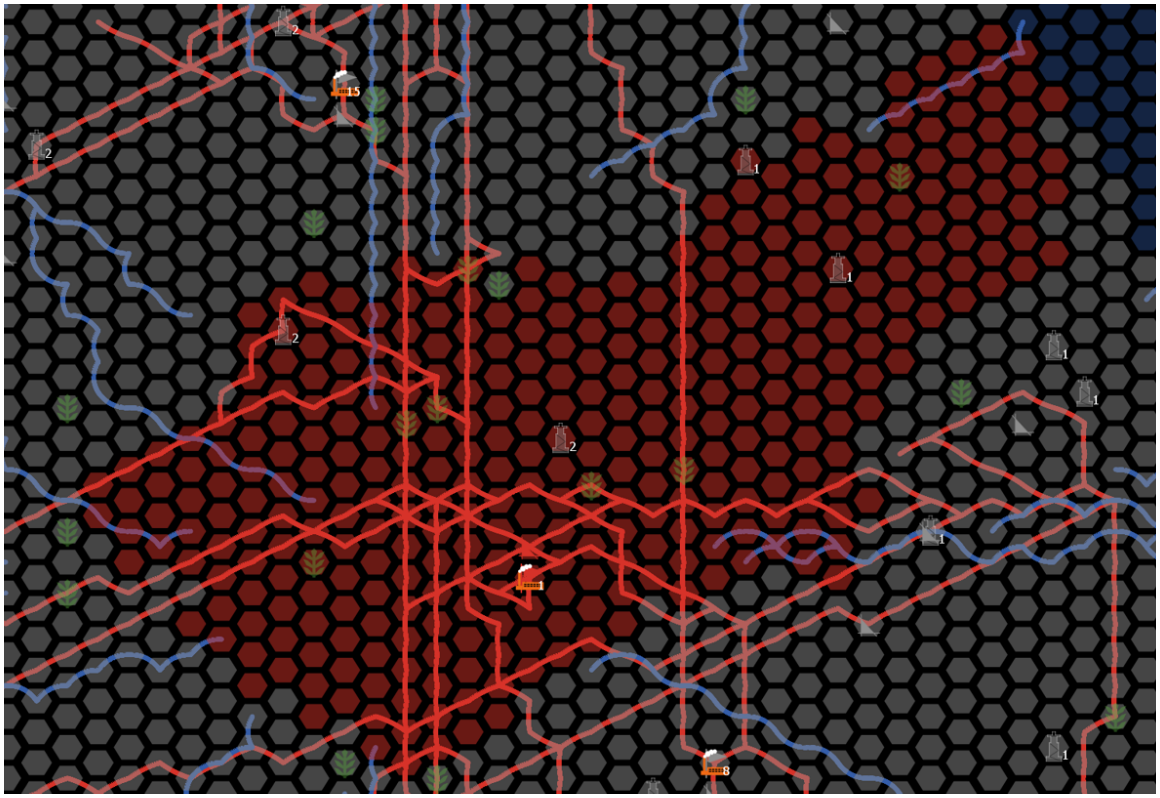

Figure 3.4: Rohan

Rohan. Player 3811 is a weak state with virtually no production and a shortage of wheat. It has the smallest military of all countries. It borders all but one country and as a long border with Mallorea.

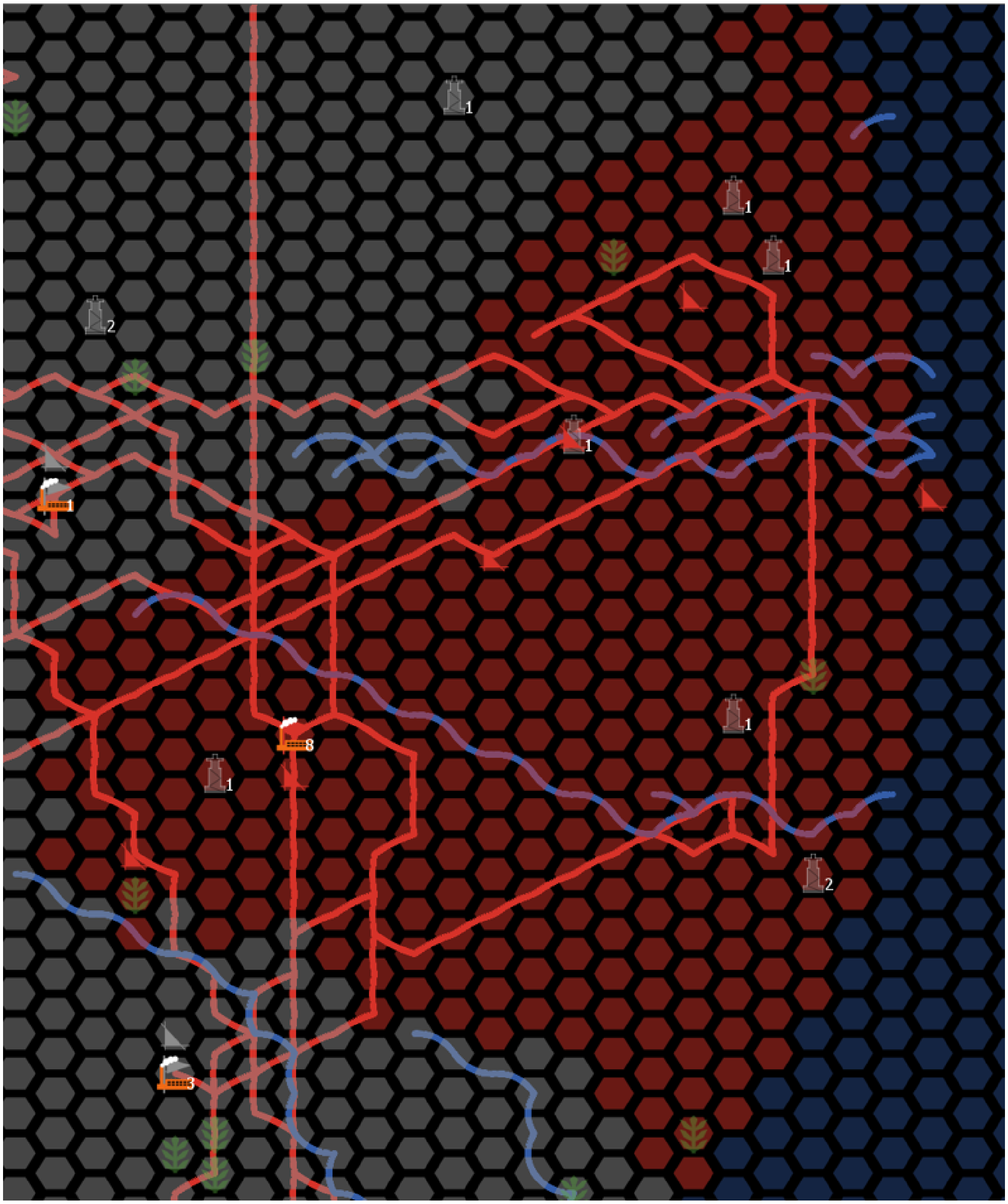

Figure 3.5: Mirkwood

Mirkwood. Player 3813 controls one of the stronger countries on the island with the second strongest military. However, Mirkwood has a significant shortage of both wheat and oil.

Its location next to Riva and Rohan, the weakest countries on the island may lead to conflict.

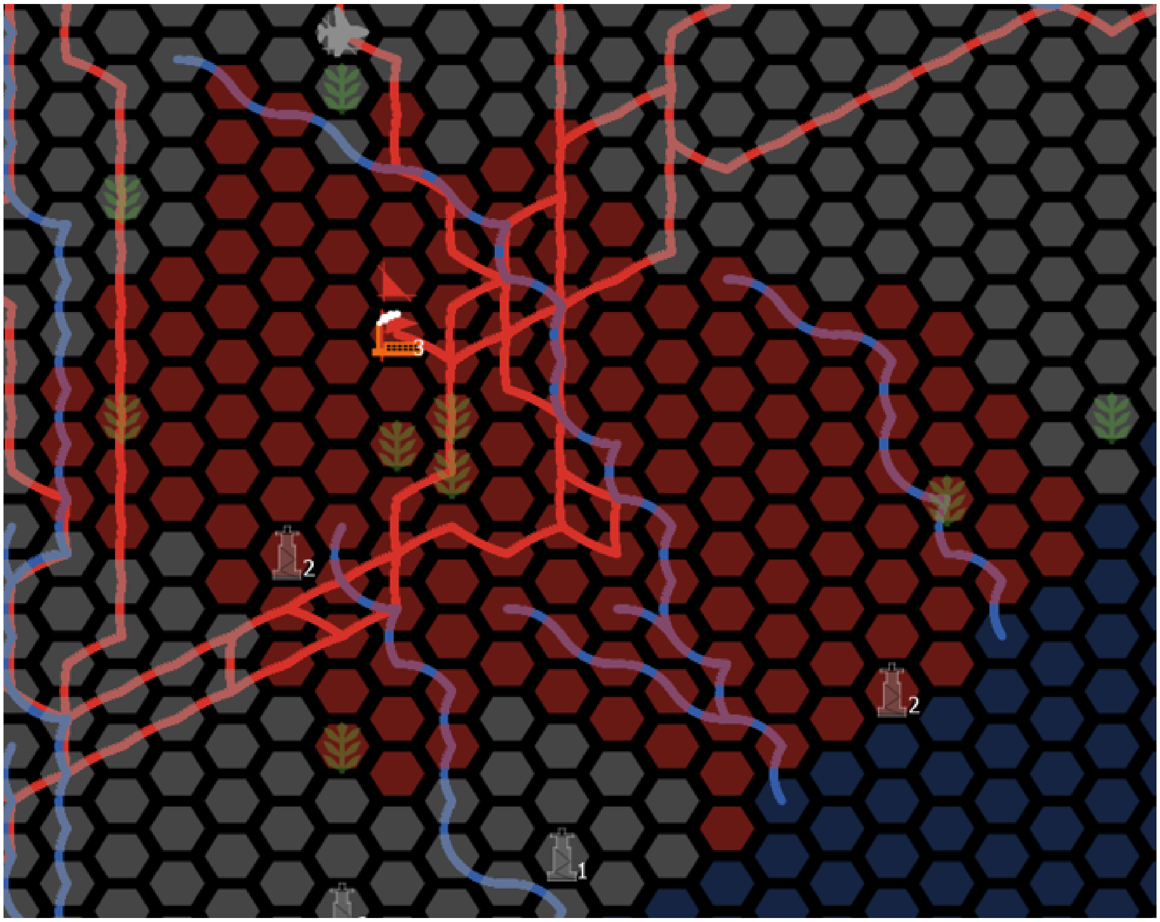

Figure 3.6: Riva

Riva. Player 3814 controls the weakest country on the island and the smallest. Bordering three other states, Riva may have some security issues on its horizon as Mirkwood is a hungry power. Riva is self-sufficient in oil and wheat.

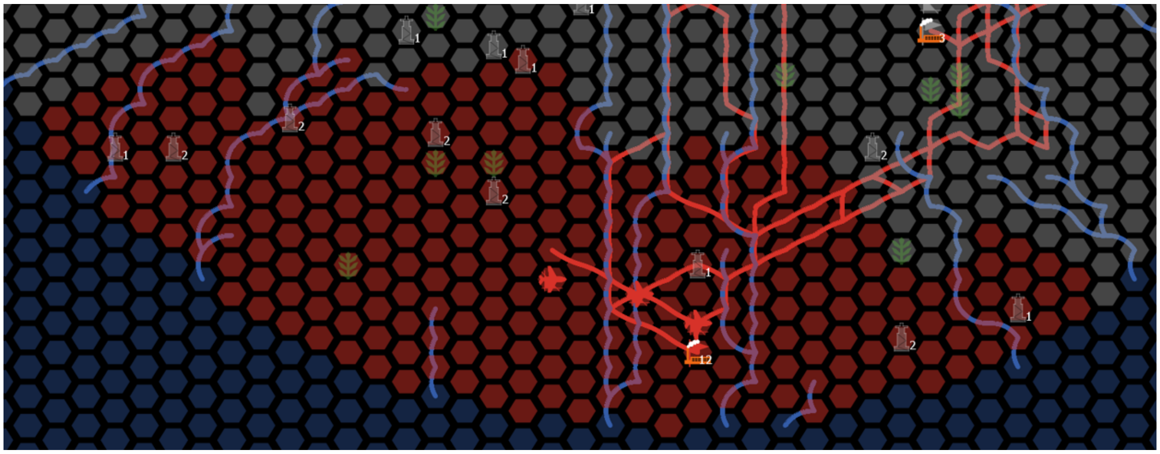

Figure 3.7: Tarna

Tarna. Player 3812 controls one of the weaker countries. However, Tarna has a surplus of wheat and oil. Its rather large production capacity may alter its position over time.

Game play begins at Turn 1. It seems clear that Mirkwood will attack either Rohan or Riva during the first turn in an attempt to quickly overcome their resource shortage.

Turn 1. Facing a significant wheat shortage, Mirkwood engaged Rohan and secured an offensive alliance with Mallorea. Mirkwood's SAC operated with impunity given Rohan's lack of air defense systems. Four Rohan ground combat factors were destroyed. Rohan lost three combat factors to Mirkwood in ground engagements while Mirkwood lost one combat factor.

Mallorea attacked eliminating five Rohan combat factors through strategic bombing. Ground engagements attrited five Rohan combat factors with only one combat loss to Mallorea.

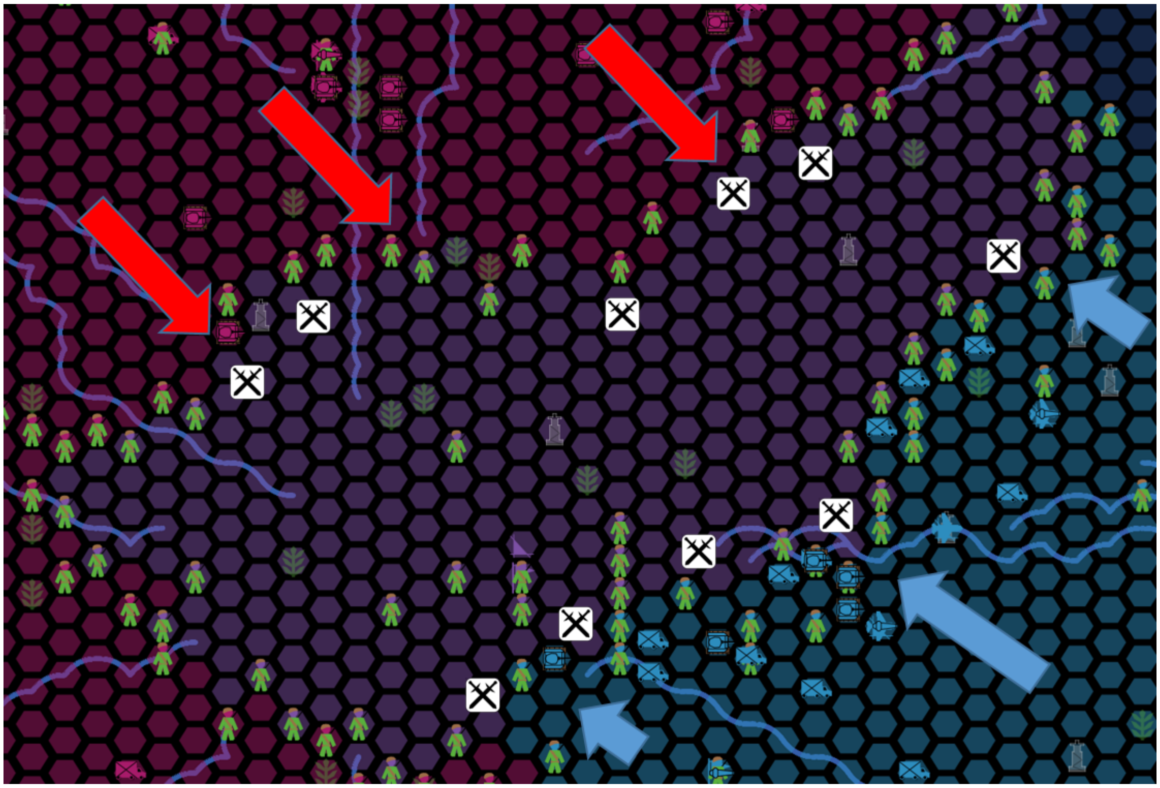

Figure 3.8: Turn 1 Invasion of Rohan

The other countries had no significant decisional conflict due to resource shortages and took no action during this turn. As resource shortages and alliances are the only motivations for state action within the current version of Enhanced RealLand, these players will take little to no action during the duration of the simulation described here.

Turn 2. Mirkwood and Mallorea continued their engagement against Rohan allocating less forces to the engagement as Rohan has suffered significant losses. The bombing campaigns destroyed nine Rohan combat factors. Two additional Rohan combat factors were destroyed in ground engagements.

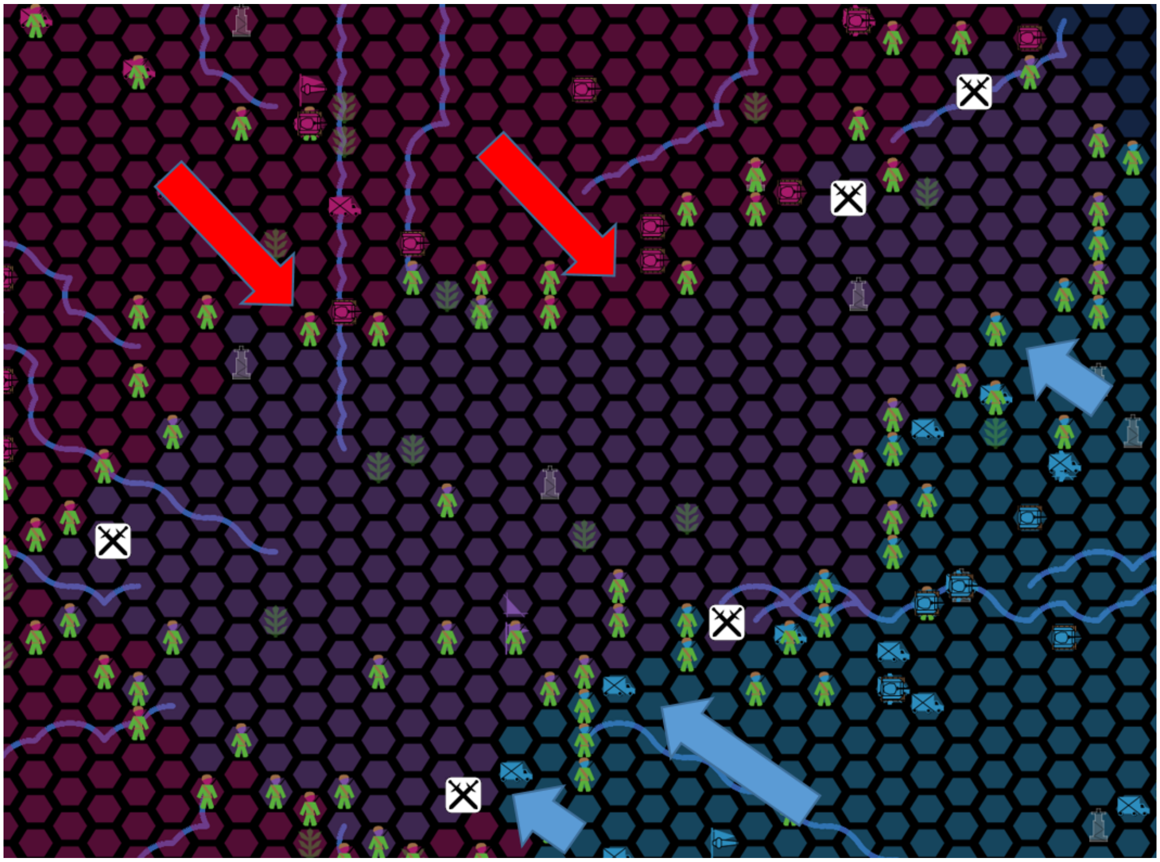

Figure 3.9: Turn 2 Invasion of Rohan

Rohan's forces were in disarray and unable to mount a coherent defense.

Turn 3. The conflict continued where Rohan loses additional forces and both Mallorea and Mirkwood continue to advance.

Turn 4. Mirkwood believed that war with Rohan was an easy victory. It did not seek continued engagement with Mallorea and continued the fight alone. In the current version of RealLand, resource shortage and requests for alliances are the only motivation for action. As Mallorea faced no resource shortages, it did not intervene.[1]

[1]Designs for several additional issues are provided in the Appendix.

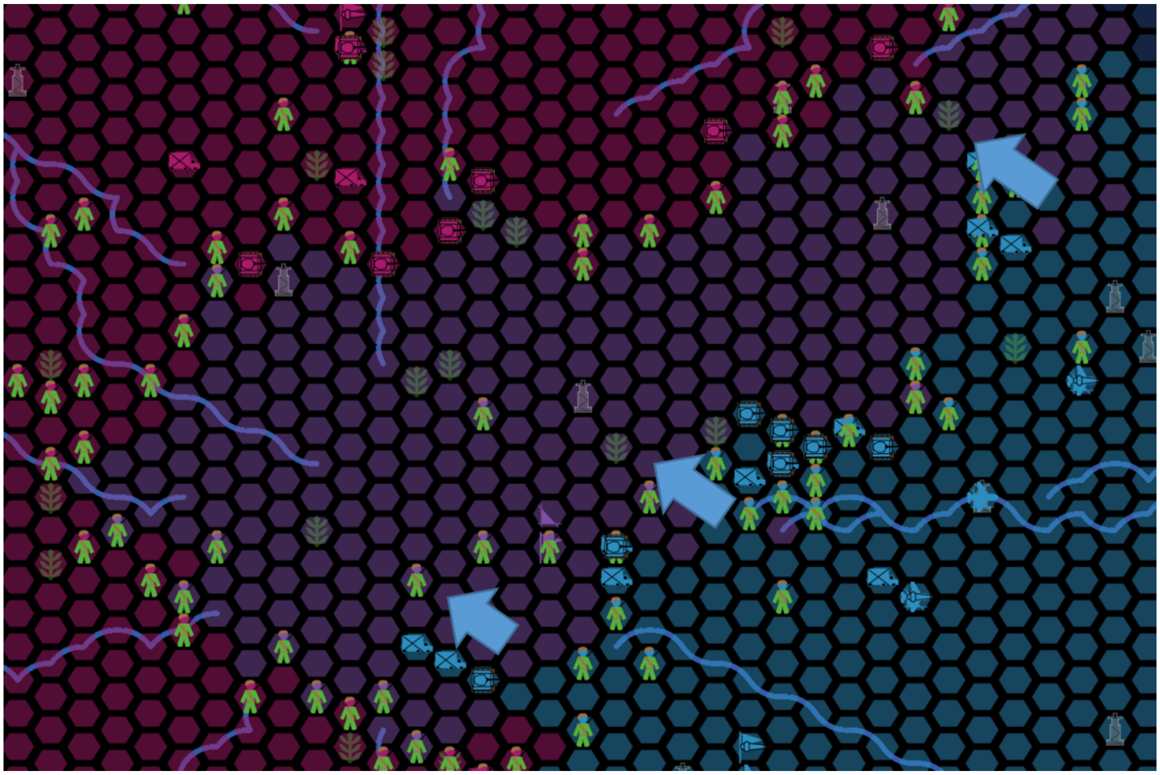

Figure 3.10: Turn 4 Invasion of Rohan

Mirkwood forces changed from a measured advance into Rohan territory and advanced straight for the wheat resources.

Turn 5. Mirkwood continued driving forward gaining two wheat. However, during their advance on the northern wheat resources, Mirkwood gained a border with Mallorea.

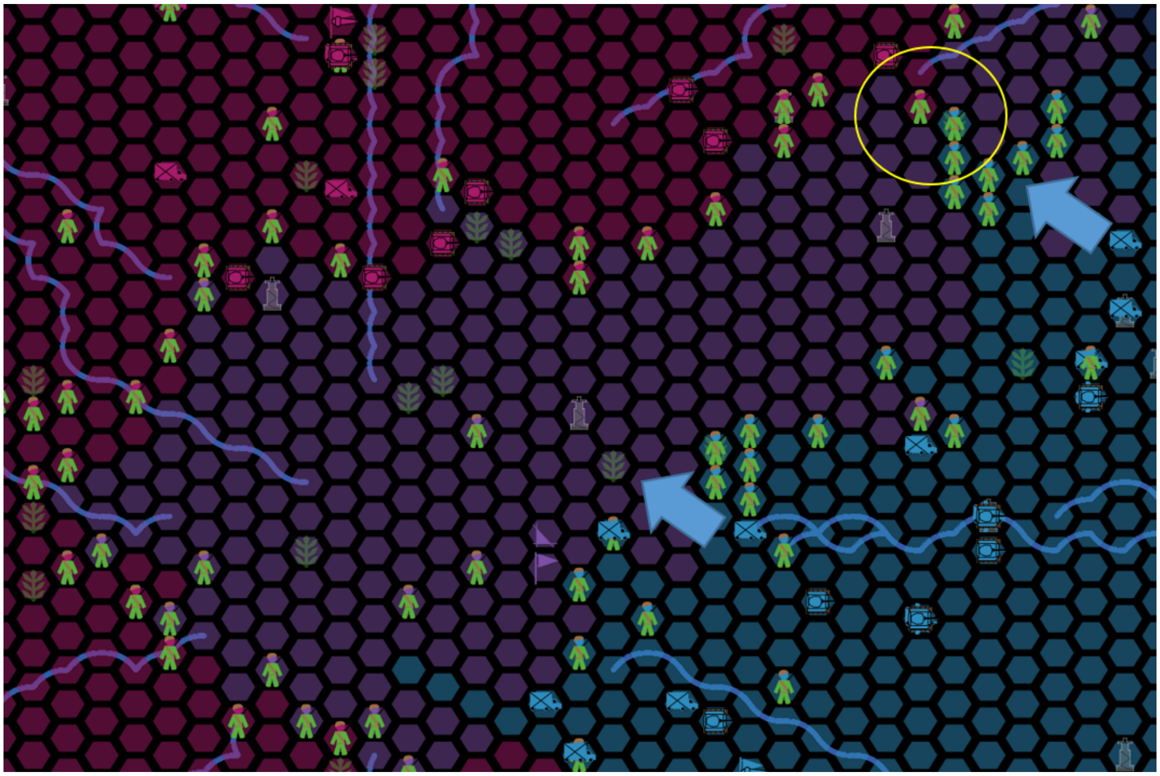

Figure 3.11: Turn 5 Invasion of Rohan

This could change the calculus for Rohan.

Turn 6. The player for Rohan saw a ray of hope as Mallorea and Mirkwood forces faced each other across the battlefield. Rohan secured a defensive alliance with Mallorea against Mirkwood. Mirkwood continued to advance during its turn, but an initial air engagement with Mallorean air forces and the loss of a wheat (formerly Rohan's) changed the situation.

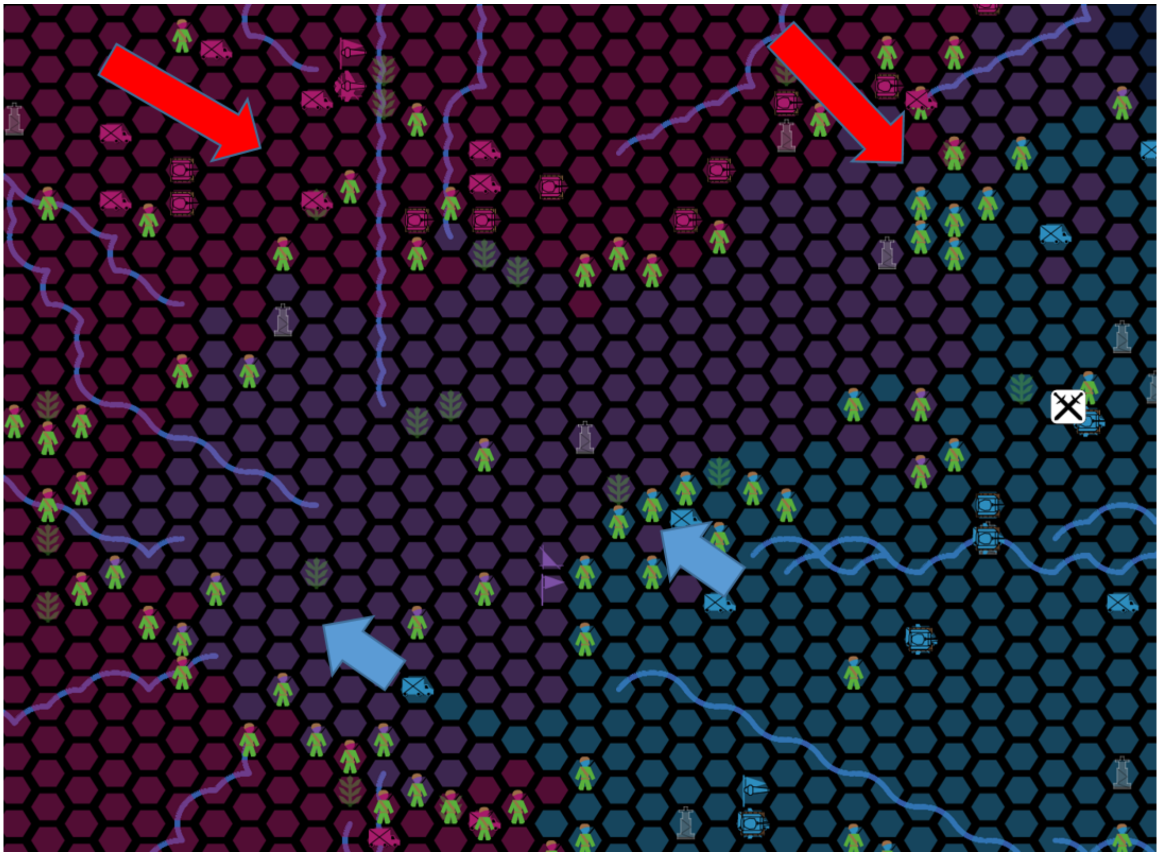

Figure 3.12: Turn 6 Battle over Rohan

Mallorea began re-positioning forces to support the defensive alliance.

Turn 7. Rohan realized the disruption in Mirkwood's progress due to the defense alliance with Mallorea. The Rohan player failed to request for additional support. Mirkwood saw no chance in winning a war against Mallorea given their advantage in productive factors and decided not to retaliate.

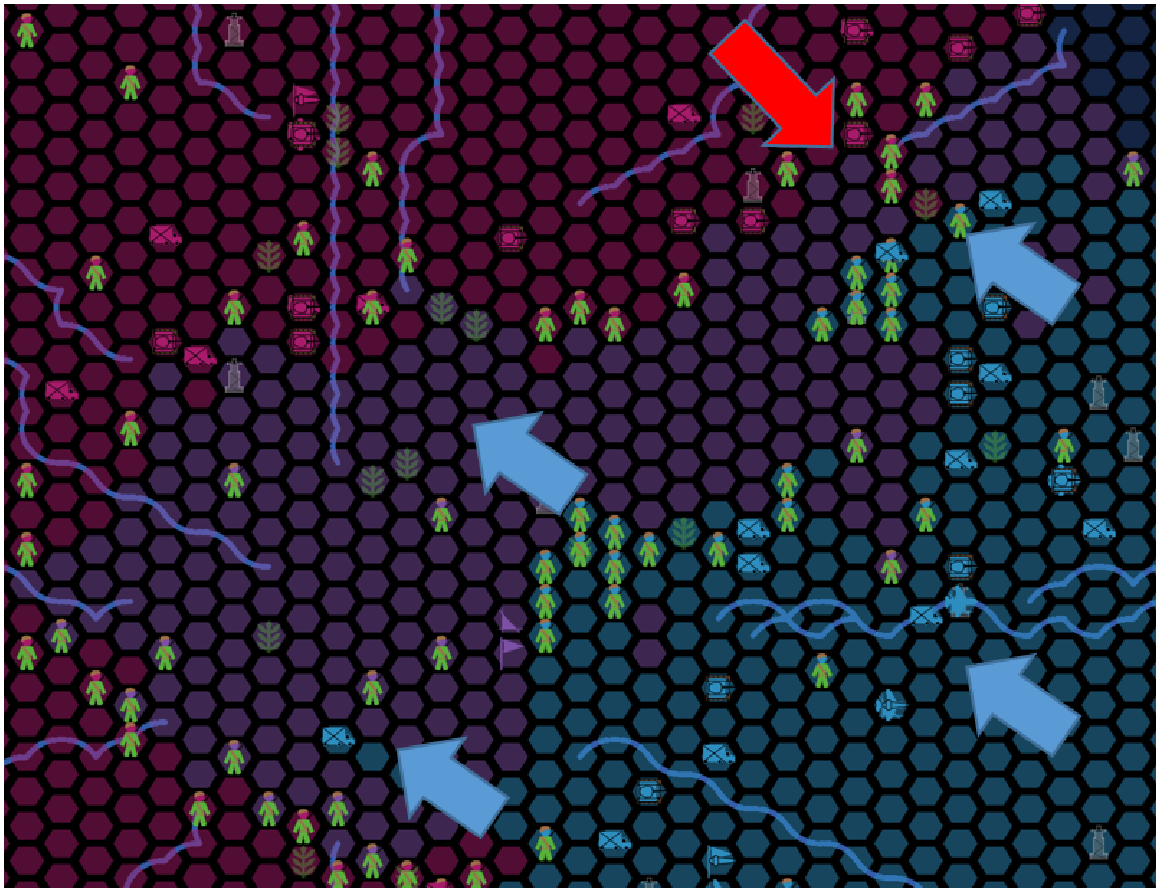

Figure 3.13: Turn 7 Battle over Rohan

However, Mallorea re-positioned forces and continued the engagement against Rohan.

Turn 8. Rohan, facing the continued Mirkwood advance, requested additional support from Mallorea. With respect to its wheat shortage issue, Mirkwood's decisional conflict was randomly advanced to vigilance. As Mallorea failed to attack last turn, Mirkwood re-positioned reserve forces.

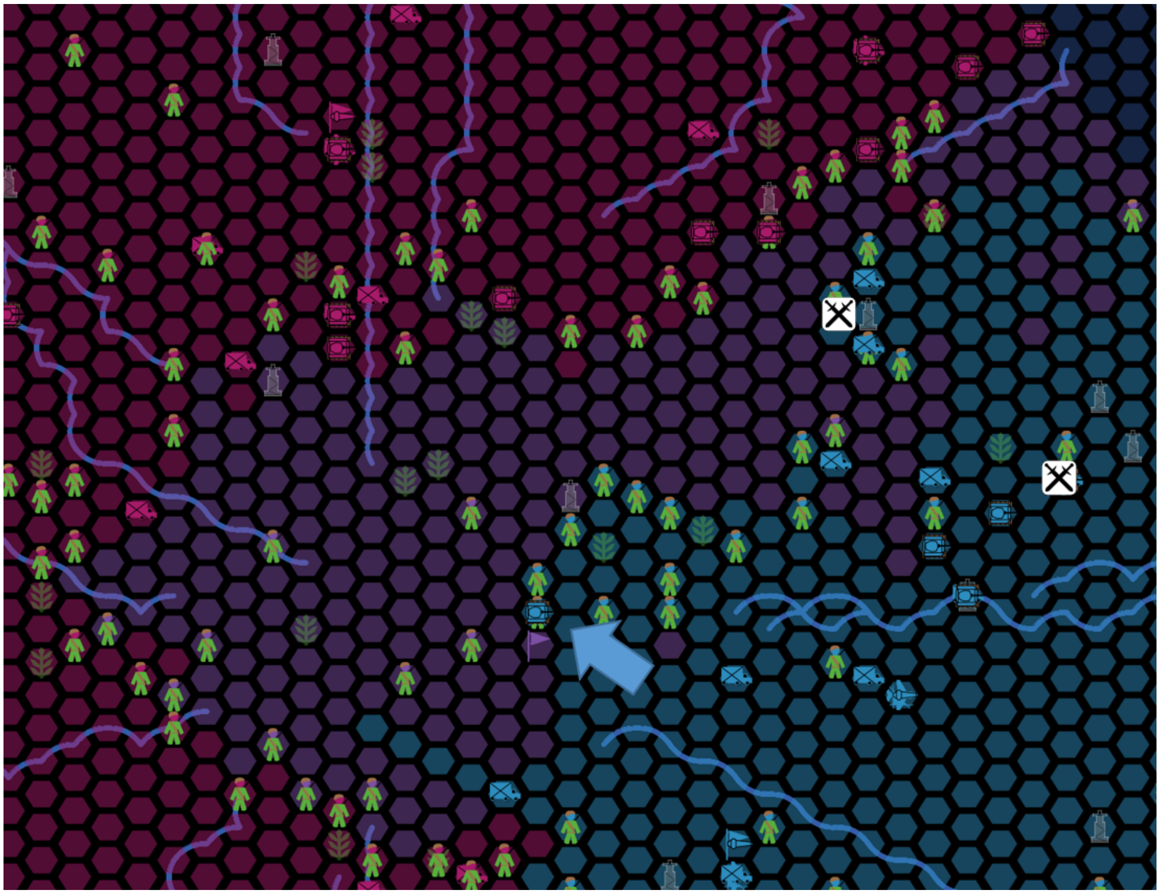

Figure 3.14: Turn 8 Battle over Rohan

Reinvigorating the conflict, Mallorea conducted successful bombing raids on a Mirkwood airbase and ground forces.

Turn 9. No attacks occur this turn. Mirkwood re-positioned forces and continued some advancement within Rohan.

Turn 10. Turn 10 is similar to Turn 8 where Rohan asked for additional aid from Mallorea. Mirkwood vigilantly advanced on Rohan. Mallorea continued to press Mirkwood's air defenses.

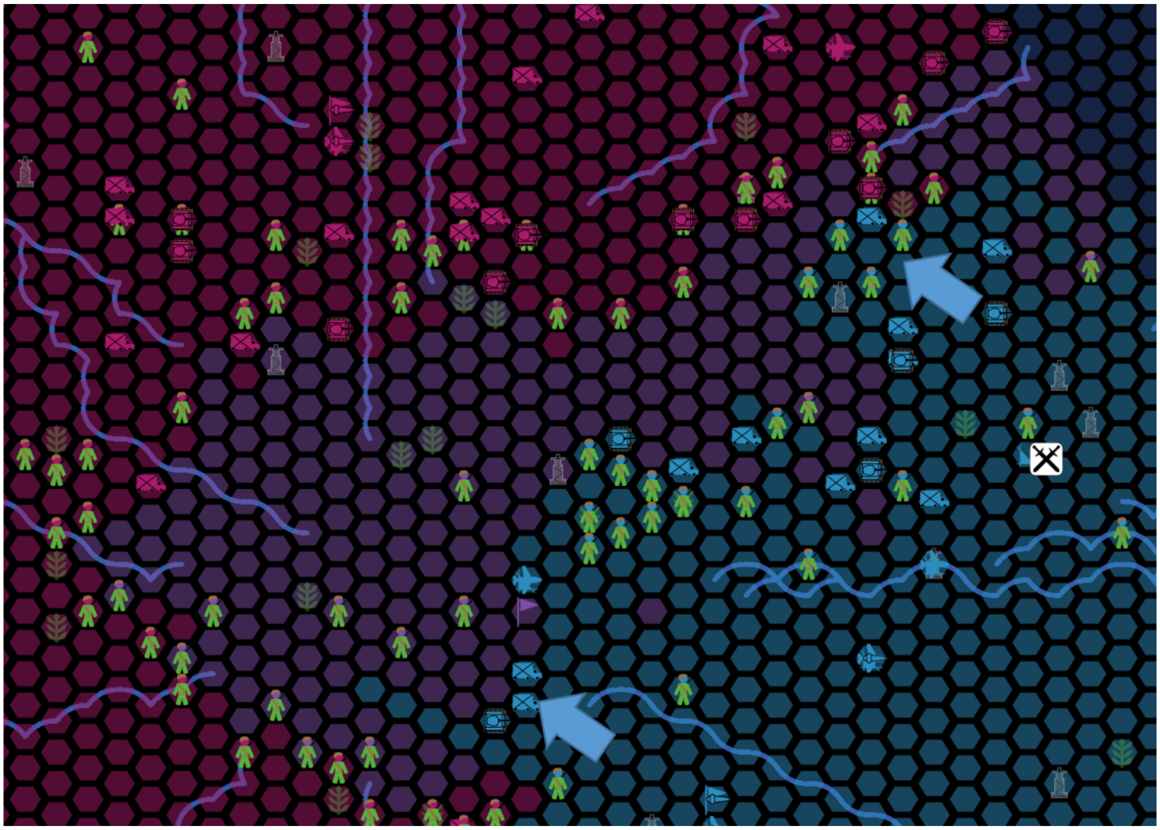

Figure 3.15: Turn 10 Battle over Rohan

Turn 11. A significant shift occurs this turn as Rohan does not request for support from Mallorea. Mirkwood was given an opportunity to respond to Mallorea's aggression during the last turn, but did nothing due to defensive avoidance. However with respect to its offensive war with Rohan, Mirkwood proposed that instead of fighting each other, Mallorea and Mirkwood should renew their collaboration against Rohan.

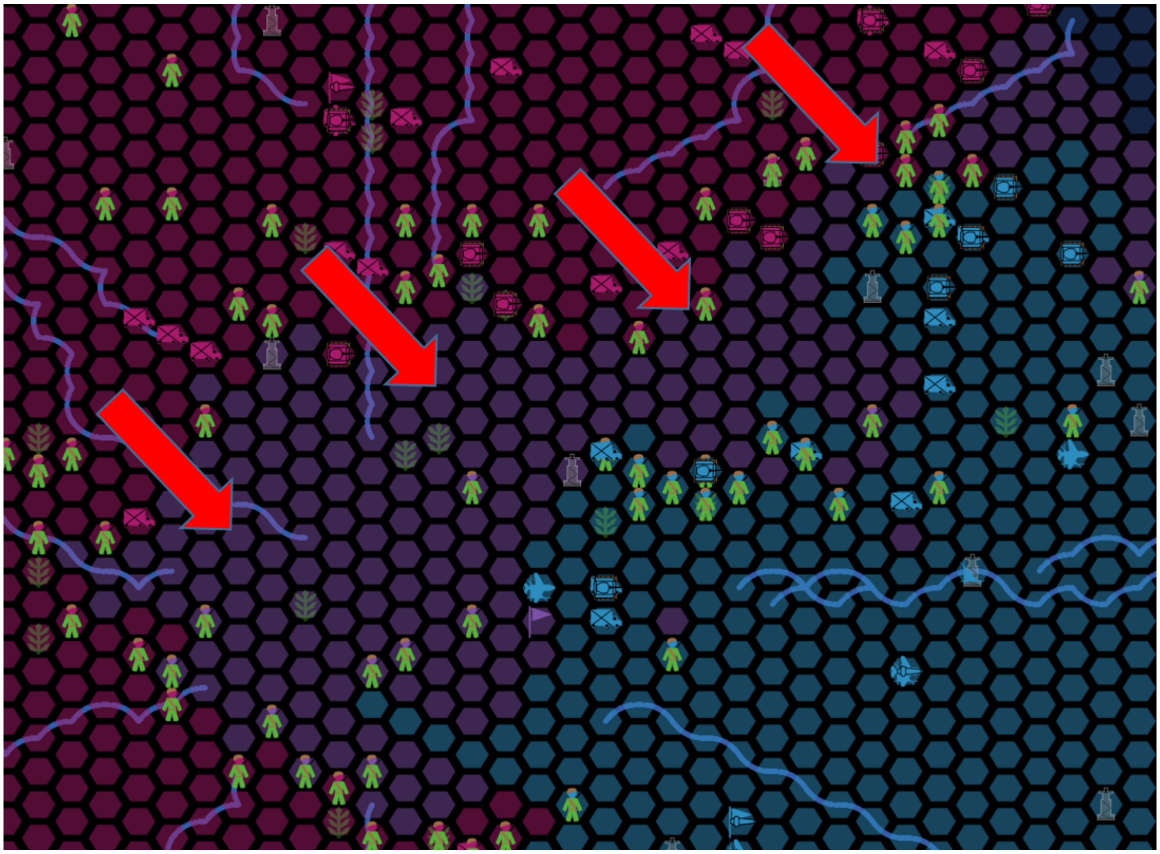

Figure 3.16: Turn 11 Battle over Rohan

Turn 12. This is a production turn. The advance on Rohan continued through the offensive alliance of Mallorea and Mirkwood. The war lasted several more turns until Rohan was divested of any useful resources.

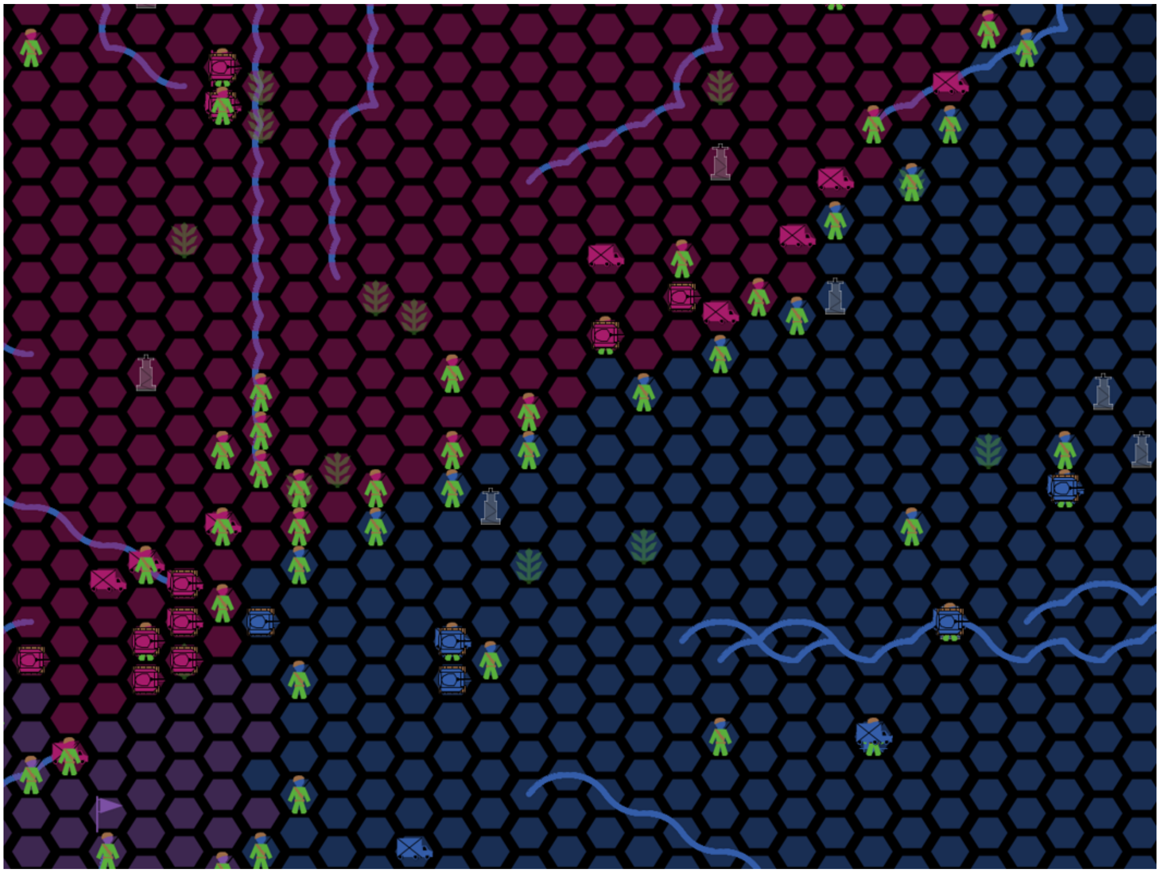

Figure 3.17: End State

S6 illustrated the storytelling feature of Enhanced RealLand simulation. Player actions were motivated by the aggression of one resource hungry player. Figure 3.18 shows the impact on national power by player. As shown, Mirkwood rose to the second most powerful country through their conquest. Mallorea grew more powerful as well.

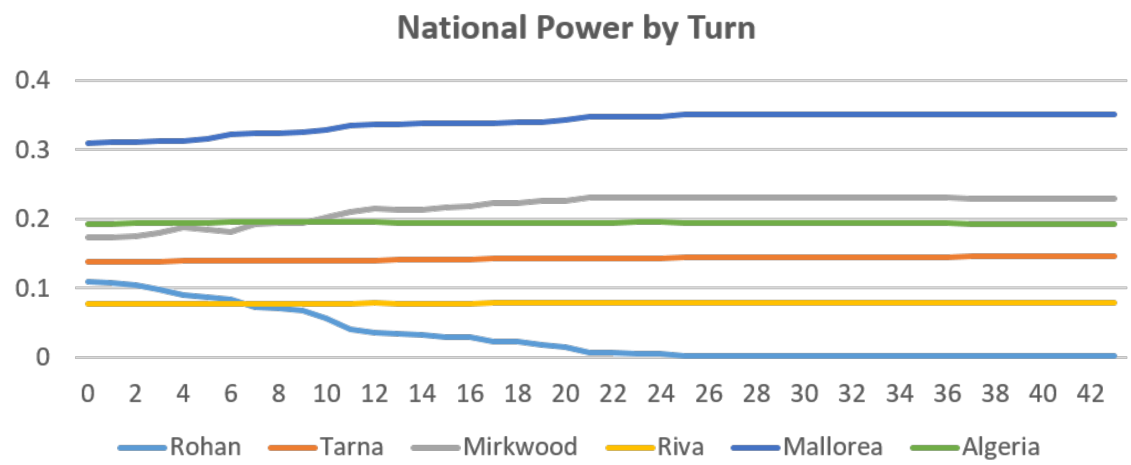

Figure 3.18: S6 National Power

Further action was deterred in the short-term. Mirkwood still had a wheat and oil shortage, but did not have the required force ratio advantage to attack its weakest neighbor as a vigilant decision-maker.

In summary, this scenario outcome is achieved based upon only two issues: defensive wars and resource shortages. For a scenario initialized with little resource scarcity, the inclusion of issues addressing position uncertainty, rising powers and balancing hungry players would have influenced the behavior of other nations.

A turn by turn history with which to analyze the individual players in a strategic-operational environment is the hallmark of a wargaming approach to computational IR. The simulation is not a game, but a virtual experience where possible national strategies are evaluated within an international system.

3.2 RQ2: Agents as Strategic Decision-makers

Can agents, instantiated with a conflict-theory model of strategic decision-making, generate key behaviors consistent with realist theory?

The critical test is whether key ideas of realist theory are illustrated in the results of Enhanced RealLand. To explore this, I will discuss the results by drawing from the excellent survey of realist theory provided in Cusack and Stoll (1990, p. 19-40).

Distribution of Power

Cusack and Stoll (1990) highlight three points of contention on how the distribution of power plays out within realist theory. Waltz (1979) agrees the distribution of power is the central mechanism that defines the dynamics within the system. However, the question becomes which distribution provides more stability- egalitariansim or imparity. Related to this is the impact of uneven growth rates. Some realists argue that uneven growth upsets the balance within the international system leading to greater instability while others assert it has no effect at all.

Figure 3.19 shows the raw occurrences of actions across 100 turns.[2] The first chart shows the occurrences of actions across the turns. The initial spike is due to the initialized state of the system where some players have significant resource shortages. The behavior of war occurrences illustrates slow and fast processes captured within the model. Within Enhanced RealLand, fast processes are those generated by resource shortages where the player takes immediate actions. Slow processes are the results of production turns where players realize their gains converting additional resources and production into military units and losses when players have been on the losing end of conflicts or trade deals.[3]

[2]Note that this is the occurrence of war actions by player- not the frequency of wars. War actions are by player so the same war could have multiple war actions by different players

[3]The results of Enhanced RealLand mirrors, at least in part, the Canonical Theory of emergence and development of social complexity (Cioffi-Revilla, 2014, p. 216). The Canonical Theory assumes slow and fast processes that drive increases in social complexity. Applied to Enhanced RealLand, a player may or

The trades are executed immediately as players seek easy solutions for addressing resource shortfalls. However, trades are executed, as needed, over time as trade deals are either re-looked, or a player now has something to trade that another player wants. This behavior is fairly consistent with past runs of the *Conflict* wargame (Selke, 2004). Trade deals are made during the first turn as players scramble for resources and are far more infrequent over time.

may not a sense a resource shortage. If they do not perceive a resource shortage or consider it not very important, the player will continue unaffected. If a change does occur, an issue is generated and decisional conflict may result. If no action is taken (i.e. defensive avoidance), the result could have poor consequences. If action is taken, it may fail perhaps due to rashness. However, adaption may occur through vigilance as additional and more measured steps are taken to address the shortage. The fundamental ideas within the conflict-theory model and the Canonical Theory share some common ground.

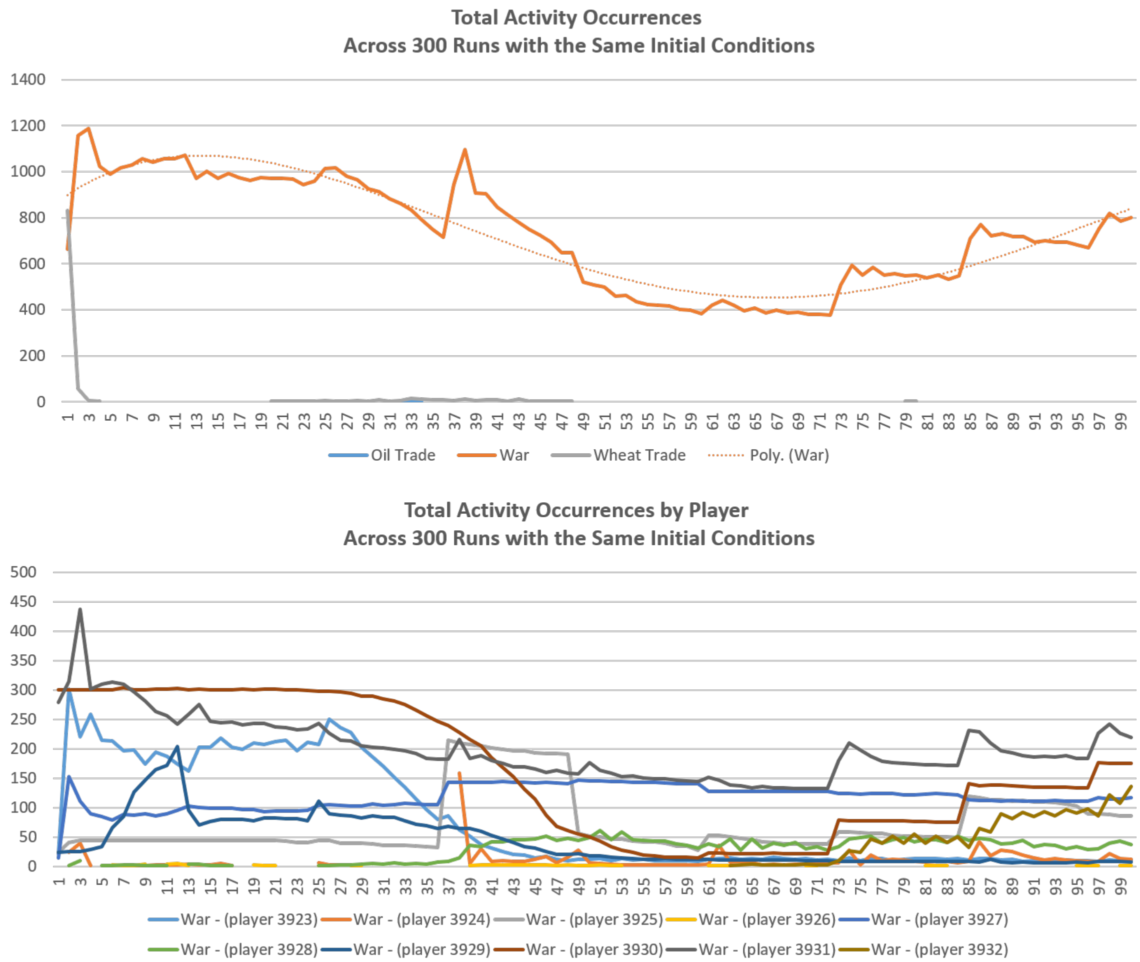

Figure 3.19: Activities by Occurrence

The second chart tells a similar story, but by player. Agents take action to solve their current problems. While through the production cycles, trade realignments, and resource development, the structure of the international system itself changes over the long-term. Change upsets the balance within the international system leading to greater instability.

To address the realist question on which distribution, egalitariansim or imparity, provides more stability, a design of experiments would be needed to explore the impact of power distribution and polarity on system stability. This will be an important element in future work.

Decision-making

According to Cusack and Stoll (1990), realist theory has some contention on the role of rationality in decision-making. Some realists argue states as rational actors that maximize expected utility. Others believe states are simply goal-directed.

The conflict-theory model has already been discussed at some length as an alternative to the expected utility functions and complicated equation-based processing of computer agents representing nation-states. Enhanced RealLand has a contribution to the discourse regarding decision-making and emergent results.

Figure 3.20 shows the average resource issue salience over the course of the simulation. Issue salience associated with resource shortage is on a scale from 1 to 4. Unconflicted adherence is 1, unconflicted change is 2, vigilance is 3, and hypervigilance is 4. The decline in wheat shortage is expected, but the rise in oil shortage that occurs towards the end of the run explains the uptick in war action frequencies previously discussed.

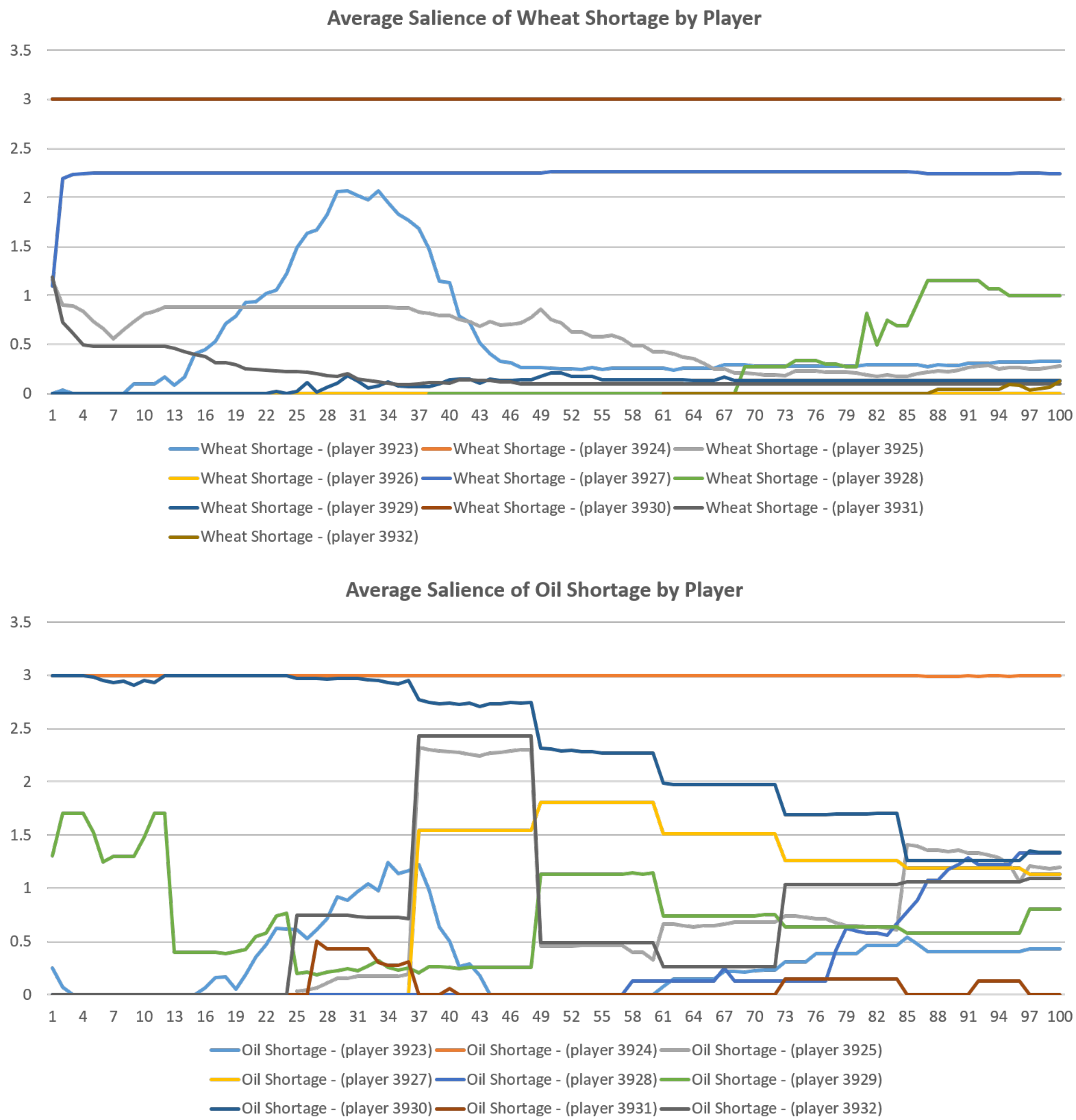

Figure 3.20: Issue Salience by Player

What is interesting is the lack of hypervigilant decision-making with respect to issue shortages. It never occurs within the baseline stochastic runs. According to Janis and Mann (1977), *hypervigilance appears to be a relatively rare reaction, largely confined to certain limited types of decisions... Perhaps the relative infrequency of hypervigilant reactions is* *attributable to the rarity of the prime antecedent conditions that we postulate for the appearance of this pattern* (p. 81). The antecedent conditions being the hope for a solution but the perception of little time to achieve it. Within Enhanced RealLand, hypervigilance is the path to rash and often risky behavior. For resource issues, hypervigilance is programmed to occur when a player is facing a resource shortage of significant duration and its power is decreasing relative to the other players. The assumption of rationality at the state level could be due merely to the reality that the antecedent conditions of hypervigilant behavior occur infrequently.

War

Cusack and Stoll (1990) describe three technical assumptions that realists debate with respect to wars and the international system. The first is that initiating war is a low risk proposition with respect to national power. Therefore, engaging in war has few drawbacks to the individual state and the plurality of the international system. A related point is that war is not decisive; thus, any victory is limited. An alternative perspective is that war provides significant cost even to the winners. In this case, a state's survival is at risk when engaging in any conflict. A final point that is present in realist thought is that greater power assures success in war. This suggests that the strong continue to get stronger. However, other realists provide a counterpoint that war is risky and unpredictable where a quick success in one campaign does not lead to additional success.

Enhanced RealLand models war as a set of military engagements. However, a player must first choose to engage in war against another player. Military action is only performed if the engagement force ratio threshold is met. This ratio is the total ratio of the attacker's combat factors against the defender's combat factors. This ratio is implemented in a few parameters associated with the stages of decision-making.

When in a state of unconflicted change, a player must have at least a 6:1 overrun engagement ratio to consider a military option. In this case, the player believes the cost of war to be trivial. Conversely, a 1:1 ratio is used when the player is in a state of hypervigilance. For all other conditions, the engagement ratio is set at 3:1.[4]

The combat adjudication operates under the heuristic that success can occur from a ratio as low as 1:3 and failure as high as 6:1. However, combat will only occur based upon the air and ground combat ratios. In the hypervigilant case, ground units may engage at a 2:1 or even 1:1 local force ratio. The question is how much risk a player is willing to entertain. Within Enhanced RealLand, a 3:1 engagement is decidedly more positive and this ratio is used by vigilant decision-makers.

In Basic RealLand, a conquering state assimilates new territories into its power calculation. Similarly, taking additional territory within Enhanced RealLand is a net positive to the player unless they suffer significant combat losses. Territory adds to national power by itself. Additionally, a city, production center, or resource hex provides additional national power gains.

Enhanced RealLand provides a war adjudication system where the closer the proximity to parity with the enemy, the higher the war cost. The conflict-theory model tempers engagements by largely committing forces to battles when there is a reasonable chance of winning. Rashness is possible but it could come at great cost. Additionally, players engage in limited objective warfare during a turn targeting specific territory.

[4]Mearsheimer provides an excellent defense of the 3:1 rule Mearsheimer (1989).

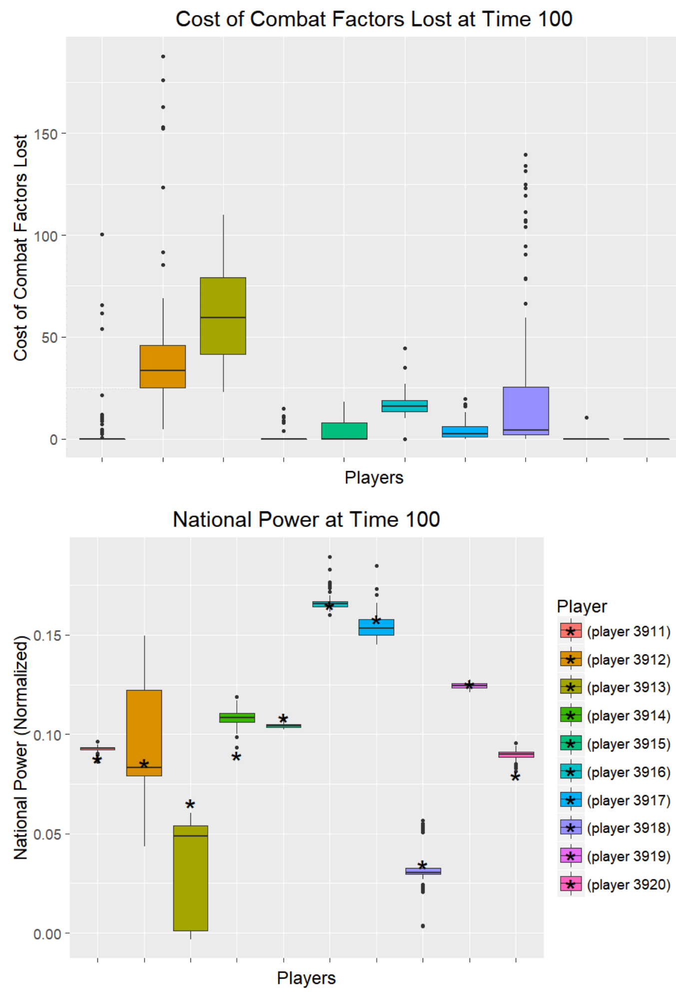

Figure 3.21: War Costs and National Power

Another set of runs, shown in Figure 3.21, is performed with a new set of starting conditions to explore the effects of war costs on national power. The first chart shows the loss of combat factors by its cost. In this case, losing a bomber costs far more than an infantry unit. The other chart shows the distribution of national power at Turn 100 with the star representing the initial starting condition. As expected, there is a moderate positive relationship between loss of military forces and national power.

However the immediate loss of national power is a temporary consideration for the victorious player as resulting gains in territory, resources, cities, and production factors can more than compensate.[5] In a uni-polar world of two players, war will pay significant benefits to the more powerful player over the long term as any losses in forces are made up in infrastructural gains.

In summary, whether war cost has an impact is almost completely dependent upon the structure of the international system and the player's local neighborhood. The stochastic loss of forces may effectively halt the attack if it slips the force ratio under the threshold. Additionally, short-term loss of combat power could have an adverse impact if the correlation of force changes. More powerful neighbors may be inclined to attack as the shift in the balance of power changes. Enhanced RealLand supports the conclusion that war costs have contextual impact.

In conclusion, a conflict-theory model of strategic decision-makers is a promising approach to depict agent decision logic and illustrate key concepts in realist theory.

3.3 RQ3: Increasing the Resolution of IR Models

How does increasing the resolution of IR models affect the findings?

Chapter 1 provides the history of IR CSS modeling. Basic RealLand replicated the early work (Bremer & Mihalka, 1977; Cusack & Stoll, 1990; Duffy, 1992) and was informed by more recent developments (Min, 2002; Luteijn, 2015) within the EARTH tradition. The original results of Cusack and Stoll (1990) were successfully replicated and explored in the analysis of Basic RealLand. Basic RealLand modeled warfare in an almost epochal way. The clash between large states resulted in significant territory losses. This section will

[5] In general with the use of force ratios, Enhanced RealLand is setup along the lines of *Si vis pacem, para bellum.* If you want peace, prepare for war.

discuss a new set of results where the conflict-theory model is set aside and the primitive power seeker decision logic and alliance structure within Basic RealLand is applied within the Enhanced RealLand environment. The metrics to explore are the presence of and time to system collapse where only a single state remains.

Enhanced RealLand with primitive power seekers is a return to the serial logic of Cusack and Stoll (1990). One initiator is selected to go to war against a target, alliance building ensues, and the initiator either continues fighting or is deterred. Once the war is setup, Enhanced RealLand adjudicates the conflict.[6] In this case, national power (Basic RealLand) was used as the primary measure as opposed to combat power (Enhanced RealLand).

[6]The initial conversion to Enhanced RealLand to handle the war intensive Basic RealLand led to further refinement of the unit movement algorithms. I completely re-factored how unit movement was being implemented though the logic remained the same. This new and improved version was used to produce the comparative results to Basic RealLand

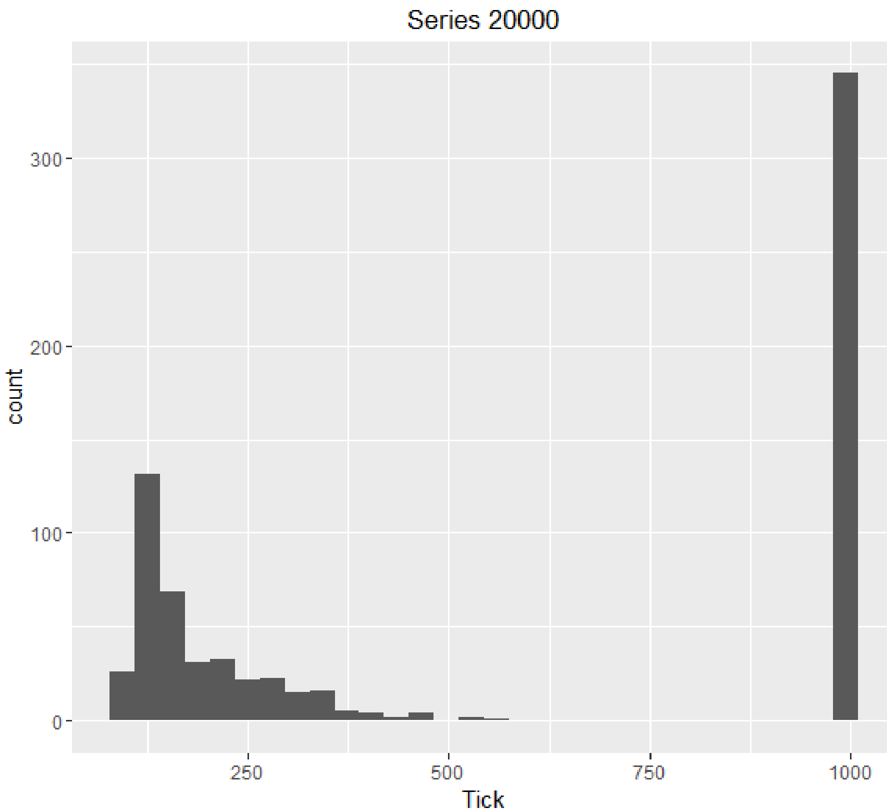

Figure 3.22: Basic RealLand Results for Series 20000

Figure 3.22 Basic RealLand results are used as the basis for comparison as the most generic of the Cusack and Stoll experiments. However, given the geographic distances and sizes of the grid space, 10 actors were initialized for 100 iterations of 1,000 turns. This took over 6 hours to execute running on 8 processors. This experiment generates new data to examine the endurance of the international system with the addition of more detailed combat modeling and production turn logic.

Figure 3.23 shows the results. The average run duration was 950 iterations with 35 percent of the runs ending in system collapse before Turn 1000. Keep in mind that the earliest a state collapses is around Turn 600 as opposed to the near immediate collapse shown in the results of Basic RealLand. The first major observation between the two sets is the continuous nature of system collapse in Enhanced RealLand. Enhance RealLand does not show the bifurcation that occurs in the Basic RealLand results.

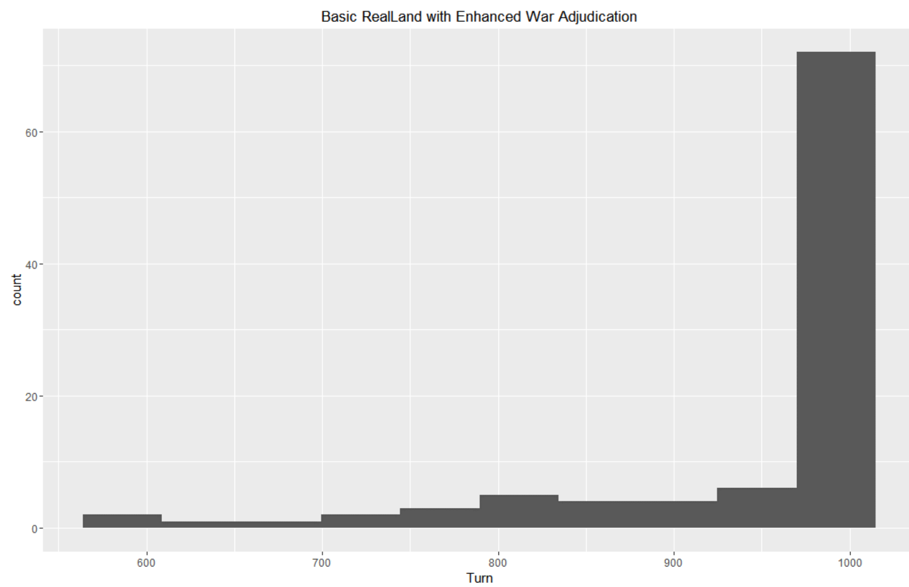

Figure 3.23: Enhanced RealLand Results with Primitive Power Seekers (100 runs)

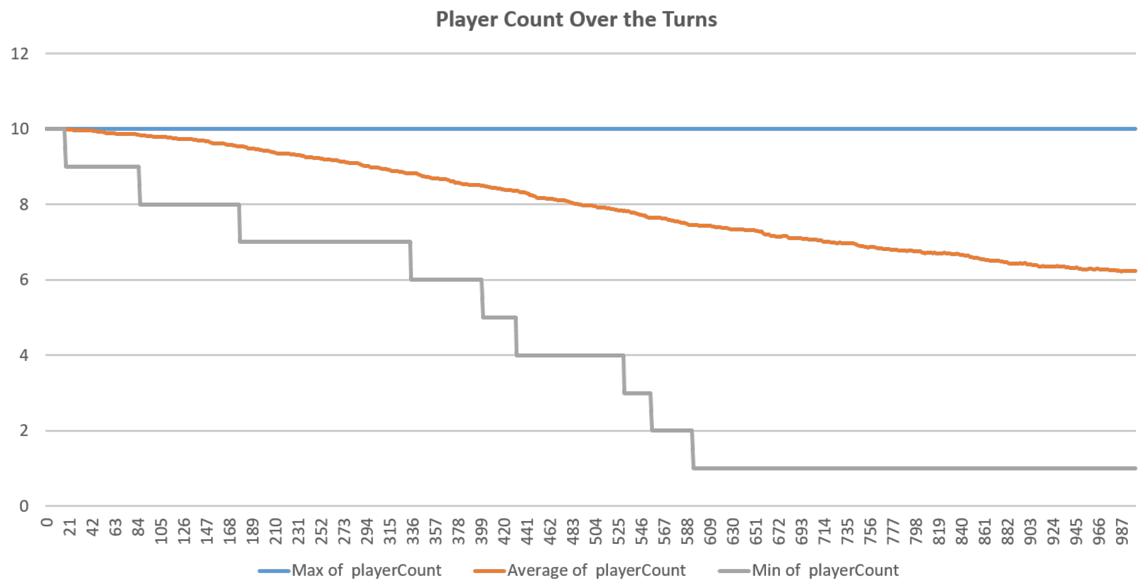

Figure 3.24: Player Count Across Turns

Figure 3.24 provides another perspective on the data. In some instances, the plurality of the system is fully maintained throughout the course of the system though in general a downward trend is noticeable. The minimum curve shows when a player is first eliminated in one of the runs. The time between player eliminations is also the duration of a war as the initiator seeks to attack another target.

To determine the chance of system endurance, Cusack and Stoll (1990) reference an empirical examination of historical systems, *noting that of the twenty civilizations that reached the stage of maturity, seven developed into universal empires* (p. 107). In the experimental runs of a 10 state system, 35 percent of the runs ended in system collapse. In addressing the research question of resolution affecting the findings, additional resolution, present within Enhanced RealLand, brought a closer result to an empirical benchmark used by Cusack and Stoll (1990).[7]

[7]There is however a cost at runtime. In attempting to run 98 initial countries with Basic RealLand agent decision-logic within the Enhanced RealLand world, I found that it takes hours for a single run. More powerful computing resources would have to be leveraged to get large numbers of agents and runs.

Chapter 4: Discussion

A promising start has been made in advancing the state of the art in computational IR through the wargaming approach. This approach incorporates wargaming mechanisms to enhance realism and the conflict-theory model to emulate strategic decision-making. This chapter will discuss the results from the previous chapter, highlight the original contributions of this research, discuss the broader implications for theory and research, and specify the future direction.

4.1 Discussion of Main Results

My research questions were decidedly of a methodological and epistemological nature due mainly to the immaturity of computational IR. To address the research questions, I developed two models in accordance with the MDIVVA protocol. The strengths and weakness are summarized in Table 4.1. As a proof of principle, I discuss the results across the two models in terms of the truth, beauty, justice, reliability, and replicability. Within social science literature, these metrics *are widely used for discerning quality in social science formal models* (Cioffi-Revilla, 2014, p. 240-242). Truth is associated with model validity answering the question to what extent does the simulation reflect real-world processes and challenges. Beauty is concerned with the accessibility of the model and its results. Justice is the utility of the model when applied to real world problems.

Basic RealLand provides a link to the pioneering models and a solid platform for researchers to apply computational IR to study international conflict. By combining the work of previous researchers and embedding within the model an easy way to replicate their exact experiments, the work is complete. Even more than that, I have added additional rigor and analysis behind the results and discussions of both Cusack and Stoll (1990) and Bremer and Mihalka (1977). This renovation of past work is not without its own merit to computational IR scientists and IR researchers in general. Basic RealLand can be used as an initial logic check or thought experiment playing out basic, foundational theories existing within the realist literature. The original intent of Bremer and Mihalka (1977) was the use of the model as a way of *integrating and synthesizing empirical research* (p. 336).

Table 4.1: Strengths and Limitations

Considerations	Basic RealLand	Enhanced RealLand
Purpose	A method for testing fundamental realist theories	A method for conducting virtual experiments on international conflict
Agent definition	Rational-choice theory and simple theory-based heuristics	Conflict-theory model
Internal Validity (Verification)	High: The model generated results of past researchers	Medium: As a new model, code reviews with additional researchers are required
External Validity (Validation, Truth)	Low: Key outputs appear to be artifact driven	Low: Key outputs show behavior consistent with realist theory, but additional tests for empirical validity are required
Generalizability (Justice)	None: The model is too abstract to be useful	Some: Shows promise in representing real-world challenges, but additional development is needed
Reliability	High: A formal design of experiments has been executed to sweep parameter values	Medium: Some stochastic and parametric analysis has been performed to understand key model behaviors
Replicability	Very High: Experiments are saved within the model with absolute precision	High: Experiments are saved within the model
Parsimony (Beauty)	Medium: The model has overly complicated equations with many exogenous variables	High: The storytelling feature is immersive and engaging

Enhanced RealLand is a proof of principle for a wargaming approach to computational IR. For my research, the model was frozen at initial operating capability, tested, and analyzed. Much work remains through iterations of the MDIVVA process to complete the overall vision of Enhanced RealLand. However, this does not detract from the present value of the model to the field of computational IR. Enhanced RealLand provides verisimilitude in detail. The world becomes far more intuitive with terrain, roads, and military forces. This is the first computational IR model to include explicit representations of ground and air combat. Mechanisms of wargaming were included to traverse the space between abstraction and realism. Enhanced RealLand is a strategic-operational simulation where players sense the world, identify issues, develop strategies in accordance with their level of decisional conflict, and implement actions such as trade, alliance building, and war. The utility is that, by the design of the operational environment, it is just as easily playable by human players on a table with some dice to handle combat adjudication.

Truth. Perla (1990) defines wargame validity as *the extent to which its processes and results represent real problems and issues as opposed to artificial ones generated only by the gaming environment* (p. 266). This is the definition that most adequately fits a wargaming approach to computational IR and one that I have used to examine the *Conflict* wargame discussed in Chapter 1 (Selke, 2004).

For Basic RealLand, the presence of a plurality rather than a convergence to a single empire happens when certain conditions are met. An initiator must seek to attack its weakest neighbor when the resulting combined defensive alliance is greater than the attacking alliance. This is an act of balancing within Basic RealLand. The analysis of Basic RealLand revealed a game-inherent mechanism. Cusack and Stoll (1990, p. 190) find that the probability of any one state surviving is very low even when a multi-state system endures. For example, any run where the world converges to three states where the dominant player believes it is less powerful than the combined sum of the other two countries, will never attack. Thus, any run of the simulation executes until this condition or a similar one is met where the initiator is gridlocked.

Even when the serial assumption is lifted, an initiator will withdraw if a less powerful state is attacking the target. The weaker states are less likely to be selected, and even if selected, the target will ask the larger more powerful state to ally, often defeating the attacker's initial will to attack. The resulting system endurance of a multi-state system is not an emergent outcome but a designed result.

With Enhanced RealLand, the objective was to construct a model more representational than Basic RealLand that could also be played by human players. The results of the validation test imply that proximity of the model's structure to the conceptual understanding of the elements of national power creates an intuition of the outcome. As the number of countries increases, this becomes more difficult by inspection. However, the fact that it is attainable is an important result. This allows for hypothesis testing and also a check on game artifacts.

As part of the verification testing of Enhanced RealLand as discussed in Chapter 2, I found that player 3930 was consistently being attacked by player 3931 and failing to effectively defend itself. Player 3931 was attacking both 3930 and 3923 in response to a request of assistance from both players. In continuing to attack player 3923, player 3930 did not marshal any forces for a significant defense. This was clearly a modeling artifact that was corrected, but it yielded additional questions. Should a player be simultaneously engaging in offensive war against a weaker opponent and defensive war against a stronger one? Should a player engage on both sides of the conflict sensing an advantage? Is a situation where a player attacks a neighbor, is attacked by a more powerful neighbor, stops their offensive conflict during the next turn to reallocate forces for defensive combat, but starts up again once they are no longer under attack by the stronger player realistic? During the Cuban Missile

Crisis, the Chinese settled a score with India when both the Soviet Union and the United States were otherwise preoccupied.

The point being that just by visually inspecting a single Enhanced RealLand run, the issue presents itself. The structure present within Enhanced RealLand provides an accessible point of departure to explore more subjective run-time decisions. Theoretical calibration is possible from both a structural and a run-time perspective. With limited additional coding, different theoretical possibilities can be explored when there is no clear guidance indicating a particular implementation.

Enhanced RealLand is far more representational than many of the IR models achieving a degree of structural validity, but its results have not been compared with many empirical data sets to achieve a high degree of empirical validity. Yet, the exploration into additional resolution within Basic RealLand proved fruitful. Cusack and Stoll (1990) drew heavily upon the empirical work of Quincy Wright (1965) on civilization development. Wright found that almost two thirds of civilizations at the time of maturity retain an international system. In the remaining cases, the civilizations had collapsed to a single empire. A similar result was achieved when generating runs with Basic RealLand with the resolution enhancements of Enhanced RealLand.

In general, the Enhanced RealLand results showed proximity to several theoretical assumptions or beliefs within realism, such as power distribution, war costs, and rationality.

- Agents take action to solve their current problems. While through the production cycles, trade realignments, and resource development, the structure of the international system itself changes over the long-term. Change upsets the balance within the international system leading to greater instability. Uneven power growth can have a destabilizing effect within Enhanced RealLand.

- The results presented an intriguing perspective on rational decision-making. Perhaps states behave rationally because there are few instances of antecedent conditions where rashness would be precipitated. Within the baseline Enhanced RealLand discussed in the analysis section, players never entered into a state of hypervigilance. This suggests that perhaps rationality is assumed because it is far more observable than rashness. However, rash behavior should not be a surprise.

- The conflicting realist assumptions on the destructiveness and decisiveness of war is to be expected. The results from Enhanced RealLand give credence to each side of the argument depending upon the situation and character of the international system. War can be a low risk proposition or the catalyst that leads to a state's own downfall through over extension.

Additionally, the model generates the kind of data, such as state survivability and systemic polarity, examined in empirical IR research. However, this output has not been explored in detail and compared to empirical results.

Justice. Justice is a measure of analytic utility where enough resolution is present within the system to engender fidelity. Enhanced RealLand provides the framework for an IR CSS model to have analytic utility whether for IR theorists, policy-makers, or educators. In the stochastic analysis of Enhanced RealLand, a single starting condition was explored. Variation in player decision-making was investigated. However, performing a formal scenario analysis on those starting conditions, could foster additional theory development and lead to generalizable results. Experiments could be run increasing a pivotal country's strength by some percentage. Results could explore system stability.

Reliability. Unlike Basic RealLand, the analytic utility of Enhanced RealLand is illustrated in the model analysis, but not fully demonstrated. Much like with Bremer and Mihalka (1977) the emphasis is on *the could be.* The hope is to continue with a more systematic analysis of Enhanced RealLand to sufficiently address the *so what* and provide decisive proof of the value of a wargaming approach to computational IR.

Replicability. If properly following the MDIVVA protocol, replicability is assured. Basic RealLand exceeds the standard in the field by directly incorporating each experimental series run by Cusack and Stoll (1990) and Duffy (1992) into the model to automatically configure the parameter values and run the experiment. Enhanced RealLand has few global parameters so parametric analysis is less complicated and saved within NetLogo's behavioral space.

Beauty. Elegance or beauty is a conceptual art form far more than a science. In social science simulations, elegance is present when the objective, conceptual model, and computational implementation exist parsimoniously in such a form as to be cognitively engaging. A cognitively engaging model is intuitive where people are able to react after seeing a result as opposed to having one explained. This is a challenging criteria for IR simulations when the referent of the model itself is largely inaccessible.

Basic RealLand is an abstract model with a large number of global parameters and complicated mathematical formulations.[1] National power is an aggregated total of controlled cells. A cell is imagined to contain resident elements of national power. The reliance on an abstract national power hurts the communication and dissemination of the model. National power is described in realist theory in terms of elements. Even at its most aggregated, it is still divided into economic (potential) and military (actual) power. Basic RealLand combines the two, but in this case the abstraction detracts from the beauty of the model.

Enhanced RealLand fares a bit better as it seeks to communicate the world almost exclusively visually. The map, order of battle, and some of the basic rules are all that is necessary to manually execute the simulation. Computer agents, like human players, pulse the environment for issues and seek to address them. The ability to visually play-test is a hallmark of a beautiful model.

[1] Indeed, the errors were complicated enough to slip into the publications.

Beyond the structure of the operational environment to support human intuition, any beauty within Enhanced RealLand is an unintended byproduct of the application of the conflict-theory model. The conflict-theory model proved an elegant modeling construct for simulating player behavior. The resulting story-telling feature, or pseudo-history by agent, so critical in social simulations (as well as other areas of computational social science) is now a feature of computational IR.

4.2 Key Original Contributions

Table 4.2 summarizes the contribution to the state of the art in computational IR.

Table 4.2: Significance of Relevant Models

	Operational Environment				Strategy					
Model	Military Units	Battles	Terrain	Resources	Production	Trade	War	Alliances	Conflict-Theory	Storytelling
Machiavelli in Machina							✓	✓		
EARTH							✓	✓		
Concurrent EARTH							✓	✓		
Emergent Polarity Model		✓	✓				✓	✓		
EARTH with Trade				✓		✓	✓	✓		
Paths to Great Power War			✓	✓	✓	✓	✓	✓		
Basic RealLand							✓	✓		
Enhanced RealLand	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Enhanced RealLand incorporated political-military dynamics. It explicitly represents military units, maneuver, and combat. Players allocate their forces against another player, decide their acceptable risk, and advance towards their objectives accordingly. Defending players must decide how to allocate their forces and whether they can risk any counter-attacks. Air combat also comes into play where achieving local air superiority provides a means to engage in strategic bombing crippling enemy air bases and ground units. The simulation of the military industrial base is also unique extending well beyond the work of the Earth tradition. This is a useful stepping stone for both the advancement and maturity of a contemporary war module for use by IR theorists and potentially policy-makers as well.

The application of the conflict-theory model where nation-states are controlled by strategic decision-makers is unique. Instantiating the conflict-theory model provides a mechanism to describe and use computer players. The bar has successfully been raised on the explanatory power of IR simulations through a descriptive model of human decision-making. It is possible to plausibly explain a pseudo-history from the player's perspective– a key element in *beautiful* CSS models.

4.3 Broader Implications for Theory and Research

The demonstration of a wargaming approach should have reverberations within computational IR. Wargaming and social simulation should be embraced and leveraged as needed in the construction of computational IR models. The playability of those approaches staves off the rush to complexity within modeling that so often plagues global models. Likewise, IR social simulation suffers from a lack of exploration as iterations are few and duration is short. The benefits to computationally exploring the scenario, before and after the social simulations, is of tremendous value. Enhanced RealLand provides this capability.

The EARTH tradition rests upon thought experiments of Bremer and Mihalka (1977). Computational IR has suffered from relatively few researchers verifying and extending past work. Basic RealLand successfully replicated and expanded the EARTH tradition. With Enhanced RealLand, I hope to provide a similar launching point for others to improve upon the simulations.

Enhanced RealLand is a significant step towards meaningfully applying computational IR to address real world problems. The foundation has been built to incorporate empirical data and IR theory to perform detailed scenario analysis. With some maturity, RealLand will support IR research and policy exploration for years to come. This work is the vanguard to more verisimilitude in detail while retaining the analytic utility.

Perhaps the most significant implication is the propagation of the conflict-theory model as a means to represent agent decision-making both within computational IR and across computational social science. The field could benefit from more direct course work in descriptive human-decision making as described in Janis and Mann (1977) to provide alternatives to mathematically intensive rational choice methods or overly simplified bounded rationality mechanisms.

4.4 Future Directions

Future direction is divided in three sections. The first section addresses the conceptualization of Interactive RealLand. The second section discusses approaches to additional empirical validity. The last section introduces potentially insightful applications of Enhanced and Interactive RealLand.

4.4.1 Interactive RealLand

Snyder (1963) makes the point that simulation for research and simulation for policy analysis are, in practice, almost antithetical to each other, due to relevancy and time constraints. The challenge appears to be in the problem and how it is formulated. Policy problems must be formulated into theoretical challenges and vice versa. Even when admitting that simulation appears useful for mixed pure and applied research, Snyder refuses to generalize on whether the same simulation (computer or social) can meet both needs. The simulation mechanism needs to surface the recurring type of crises faced by policy-makers and provide the mechanism for them to address these issues during the simulation. Presciently, he outlined an integrated path forward that leverages the complementarity of the different forms of simulation (manual, constructive, and hybrid). Constructive simulation is very attractive in forcing a concrete definition of a theory. Once done, the analytic ability is a significant contribution to the testing and exploration of concepts. However, humans are able to address the qualitative realities that are difficult for the computer to interpret. It may take a programmer weeks to code what a human being executes in a few seconds of studying the problem. By engaging human participants in a creative process, social simulation allows for knowledge creation outside the test itself. This is not easily gleaned from a regression analysis of simulation output (Snyder, 1963, p. 16). Despite its value, the reality of social simulation is the cost prohibitive and time constrained nature.

Ultimately, the pursuit of IR simulation is the coalescence of human ingenuity and computing power in the discovery of possibilities. Building upon this work, the Interactive RealLand simulation is designed to enable social simulation and analytical computer simulation of the same problem space. Interactive RealLand could be constructed within available wargaming software to assist human players in executing the Enhanced RealLand simulation. The ability to translate the operational environment between Enhanced and Interactive RealLand would allow for considerable analysis and research.

The first obstacle to overcome is the technical challenge of docking the two simulations. This can be accomplished through the use of a system-style, computer adjudicated wargame and Enhanced RealLand. Interactive RealLand leverages recent advances within the defense community to specifically enable computer assisted military wargaming.[2]

Interactive RealLand has the potential for being the most cognitively engaging form as results can be understood within a computer-assisted social simulation environment like SWIFT. Figure 4.1 shows a notional example of a Korean scenario including airbases and military icons. Visualization within SWIFT is multi-dimensional as actors or units contain data that is easily inspected upon a click and aggregated in numerous views. Layers and filters can be applied to customize the visualization and the story can be told across the

[2] I have been granted permission to use the software to support my research. The Standard Wargame Integration and Facilitation Tool (SWIFT) is a US government-owned human-in-the-loop wargaming engine designed to provide computer-aided support to wargames ranging from simple visualization and recordation of player moves to a fully automated computer game that instantiates complex rulesets that are a facet of most modern warfare board games. As a game-agnostic tool, SWIFT accommodates unique professional game designs by enabling users to build, play, and analyze their games. Its inherent open architecture allows for users to bring their own methods, models, and tools to bear within the game without being subjected to embedded hard coded solutions.

turns. A cognitively engaging view is one that takes little effort to inspect and understand. Few computer simulations are crafted with such an end in mind.

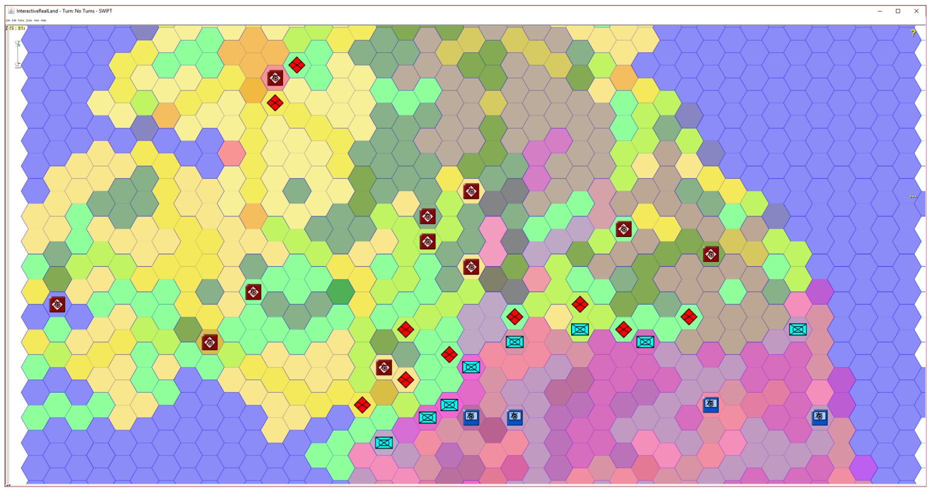

Figure 4.1: Interactive RealLand: Playable Space

This cognitively engaging view is not so easily accomplished within Enhanced RealLand, but the results of illustrative or important runs could be integrated back into the SWIFT environment. A broader methodological contribution could be to change the way IR researchers and national security analysts consider social and constructive simulation. The pedagogical value of an interactive simulation, capable of both manual and constructive execution, to teach and explore IR theories is not to be understated. As such, a future direction of research should be to execute Interactive and Enhanced RealLand as a set of social and computer simulations.

4.4.2 Approach to Empirical Validation

Enhanced RealLand currently provides three main types of output. The first type is country data by player and turn including cities, oil, wheat, production factors, total area, technology level, national power, combat factors, percentage of rough border terrain, risk tolerance, combat factors lost, and player count. An augmentation would be to provide not only national power but the polarity of the system leveraging metrics described in Cederman (1997) and Min (2002). Enhanced RealLand does not currently provide a count of the neighboring players as an output. The second type is action output data by player and turn. This contains the details on trade and war. While war actions are provided, a cleaner output providing the number and duration of wars would be warranted. Wars could include duration and cost. The third output type provides issue data by player and turn to include the salience of each issue. This could allow for correlation between decisional conflict and state survivability. A major gap in data output is the direct history of interactions between states including offensive and defensive alliances. Enhanced RealLand could be modified to provide that data more directly, and perhaps even incorporate a history of interactions between states within the agent decision calculus.

For theory development, the same techniques for empirical analysis could be applied to Basic and Enhanced RealLand to build data-driven models (DDM). Statistical analysis is a major component of IR scholarship, as researchers attempt to discern patterns within empirical data. For instance, war casualty levels were found to be power-law distributed (Cederman, 2003). However, such statistical analysis usually does not provide much insight into why the distribution takes that form. For IR, computational techniques provide a solution to explore what (if any) set of factors generate that behavior.

Basic and Enhanced RealLand data could be used to generate several types of DDMs. Time-to-event or survival analysis could be used to construct a state, system, or polarity collapse model based upon simulation generated longitudinal data. The model could forecast the estimated time to a collapse based upon the structure of the international system. The simulated data could be used to generate a probability density function of the frequency of collapse. The hazard rate, which is the probability that if a nation survives to turn(t), it will succumb to the event in the next instant, could be estimated. The result could be a survival rate model for nation-states. Similarly, polarity could be addressed as well, where the hazard rate assumes the probability of system change given that the international system has survived with a particular duration to turn(t).

Another potential application is to apply a graph-theoretic approach similar to Harary and Miller (1970). Here the objective would be to illustrate the relationships between nations through a series of matrices addressing reciprocal defense relations, trade, and potentially other factors. From a simulation perspective, this data would enrich the resulting inductive model of alliance formation and destruction over time. It may be possible to make predictions of system stability based upon the relationship schematic. Some alliances structures may be more robust than others.

Ultimately, evidence of empirical validation of a computational IR model is the emergence of and approximation to empirical regularities in IR. Statistical tests are easily performed comparing the simulated and empirical distributions. In the cases where no empirical data set has been developed, the simulated results could be used to guide the effort.

4.4.3 Relevant Scenarios for Application

Computational IR applications have long focused on system stability within *bounded, independent, territorial systems* (Cusack & Stoll, 1990, p. 22). Basic RealLand could be used for this purpose selecting, for instance, ancient China between 1122 BC to 221 BC. After instantiating the elements of power and polities of the starting period, Basic RealLand could explore and test the impacts on system stability. However, Enhanced RealLand has a much wider application. To discuss the applicability of Enhanced RealLand, I propose two historic use cases, two current challenges, and two hypothetical future applications. I discuss what the model can do now and what it will do when it matures its agent logic to more fully represent strategic decision-making.

Historical Applications

As a first application, Enhanced RealLand would be will suited to model the Greek history from 700 BC to 338 BC based upon Sealey (1976). The key issue to explore would be the probability of the rise of Macedon. Does the multi-state system collapse by 338 BC? Do structural factors alone indicate its rise or was it a chance event? The current version of Enhanced RealLand could look for resource acquisition, defensive, and offensive alliances as a motivation for state action. Further maturity would provide more dynamic players taking actions to secure their individual power and their nation's place within the international system. An advantage of exploring the Greek System is that it would be well suited for the parallel application of both Basic and Enhanced RealLand. The bounded nature of the Greek system lets the influence of external states, such as Persia, be exogenous to the model. A key question would be whether or not Enhanced or Basic RealLand could forecast Macedon's rise to power.

The second application would present a similar situation with the rise and expansion of a Prussian Kingdom from 1600 to 1815 (Clark, 2009; Friedrich, 2012). Enhanced and Interactive RealLand could provide insights ultimately into German Unification. Prussia began as a weak Baltic state, but ultimately had a tremendous influence shaping the future of the Europe. Enhanced RealLand could be applied to first capture the strategic perspective of the various state actors during that time period and understand their motivations of action. This application would first explore resource acquisition as a driver of international conflict and with additional maturity incorporate a wider range of internal and external dynamics as motivations for international conflict. Again, a key question would be whether or not Enhanced RealLand could forecast Prussia's rise to power. This would be the first scenario for testing the synergy between social and computer simulation. Interactive RealLand could be used to capture the dynamics of actual players and feed those insights back into the design of Enhanced RealLand for that scenario.

Current Challenges

The current version of Enhanced RealLand can be applied with some ease to the force structure and combat that existed before the modern era of combined arms and precision guided munitions. Addressing current challenges would require implementation of additional wargaming mechanisms from the *Conflict* wargame that were alluded to in its design. Assuming its maturity in both operational environment and agent decision-making, Enhanced RealLand could be applied to current day challenges of international conflict.

The first application could be the exploration of the security of the Baltic states against Russian aggression. Estonia, Latvia, and Lithuania are currently NATO countries in a dubious position within the assertive Russian sphere of influence. Enhanced RealLand could be used to explore a series of *what if* questions surrounding the motivations and likely actions of regional players.

The second application would be the dynamics surrounding the players competing for resources within the South China Sea. This power and resource-driven competition would be well suited for Enhanced RealLand agents.

Future Scenario Applications

Scenarios worth investigation for insight into diplomatic, aid, and trade initiatives; force prepositioning; and force application include:

- A full-blown Baluchistan insurgency in Pakistan complicated by internal ethnic and religious divisions, the lawless Federally Administered Tribal Areas, and interests and activities of neighboring regional powers. A further complication is Pakistan's possession of nuclear weapons.

- The search for a political settlement in Afghanistan complicated by ethnic and religious divisions as well as the interests and activities of regional powers. A further complication is Afghanistan's landlocked geography.

- The challenge of putting Libya back together given the internal ethnic and religious divisions, the interests and activities of neighboring and regional powers, and the activities of radical Islamist groups.

Most of the above scenarios require social solutions to the safety, security, and standard of living of the populace. Denying the ground to adversaries militarily, particularly through air power, is not sufficient. The process of tackling these problems is often called nation building. The social aspects of Interactive RealLand are well-suited for this type of investigation.

These scenarios would stretch the capability of Enhanced RealLand unless those additional features on internal dynamics are incorporated.[3] Even then, additional computational features may require pulling from a broader set of computational IR models that focus explicitly on internal domestic issues.

[3] Additional dynamics are described in the Appendix.

Chapter 5: Conclusions

The development of Enhanced RealLand, by instantiating a wargaming approach to computational IR, has advanced the state of the art. This statement is justified through an extensive literature review and assessment of computational IR models of international conflict, which are few and abstract. The review was augmented by the creation of Basic RealLand as a replication of past models. The RealLand Framework was developed through a review of the historic works of key realist theorists, and served as the theoretical guide for model development. Mechanisms were taken from the *Conflict* wargame to provide verisimilitude of detail. Most significantly, within Enhanced RealLand, I demonstrated a new approach for modeling nation-states as strategic decision-makers using a descriptive conflict-theory model of human decision-making.

Three research questions were proposed:

1. *Can a wargaming approach to computational IR be used for conducting advanced IR research, where verisimilitude in detail enhances rather than detracts from the epistemological value?*

2. *Can agents, instantiated with a conflict-theory model of strategic decision-making, generate key behaviors consistent with realist theory?*

3. *How does increasing the resolution of IR models affect the findings?*

The methodology consisted of the development and analysis of two models, Basic and Enhanced RealLand. Basic RealLand served as the link to the past while Enhanced RealLand advanced the state of the art. Basic RealLand successfully replicated and extended past work within the EARTH tradition. Enhanced RealLand illustrated its value through its storytelling feature, and achieved results consistent with realist theory.

The first research question addressed the requirement for additional resolution and the potential for usability issues that occur as model complexity increases: *Can a wargaming approach to computational IR be used for conducting advanced IR research, where verisimilitude in detail enhances rather than detracts from the epistemological value?*

A turn by turn history with which to analyze individual player decision-making in a strategic-operational environment is the hallmark of a wargaming approach to computational IR. Enhanced RealLand provides this capability. The simulation is a virtual experience where insights into possible national strategies and their probable outcomes are developed within an international system featuring diplomacy, trade, resource development, and war fighting.

The second research question addresses the ability to model agents as strategic decision-makers and retain plausible results: *Can agents, instantiated with a conflict-theory model of strategic decision-making, generate key behaviors consistent with realist theory?*

Enhanced RealLand generated key concepts of IR theory, such as power distribution, decision-making, and the contextual case of war as a tool for power acquisition. Tracking power distribution and activities overtime illustrated the distinction between short and long term processes over the course of the simulation as the international system itself changed based upon player actions. Interestingly, the incorporation of hypervigilant actions never occurred in the baseline runs. The assumption of rationality at the state level could be due merely to the reality that the antecedent conditions of hypervigilant behavior occur infrequently. Finally, war and its uncertainty is reflected in RealLand. In some cases, war has a clear value-added for the aggressor state. In other cases, the war itself weakens the state making it terminate the engagement or worse making it susceptible to attacks by others.

The third research question was designed to consider past IR CSS models and explore the impact of keeping their agent logic intact but enhancing the operational environment: *How does increasing the resolution of IR models affect the findings?*

By combining the operational environment included in Enhanced RealLand, with the agent logic and alliance structure from Basic RealLand, the experimental results on system stability better approximated the empirical data used by Cusack and Stoll (1990). While not a definitive conclusion, it is certainly an encouraging outcome. A future test could switch from artificial worlds to an empirical scenario and see how the simulation plays out historical events.

Enhanced RealLand provides verisimilitude in detail that has not previously existed in computational IR. The enhanced realism taps the potential of tightly-coupled interchanges between social and computer simulation for research and policy development. The extensible structure of adding conflict-theory modeled issues leading to trade, alliances, or war sets the stage for future development. The dream of analytic utility from computer simulation and cognitive engagement from wargaming and social simulation for advanced IR research is now one step closer.

Appendix A: Appendix

A.1 Combat Result Tables

Table A.1: Enhanced RealLand Terrain Effects on Ground Unit Movement

Terrain	INF	M INF	ARM	G	FLAK
Clear	1	1	1	1	1
Forest	1	2	2	1	2
Mountain	2	2	4	1	2
City	2	2	2	1	2
Sea	-	-	-	-	-

Table A.2: Enhanced RealLand Air Engagement Adjudication

Die Roll	1-3	1-2	1-1	2-1	3-1	4-1	5-1
1	.25/.50	.25/.50	0.0/.50	0.0/.75	0.0/.75	0.0/1.0	0.0/1.0
2	.50/.50	.25/.50	.25/.50	.25/.75	0.0/.75	0.0/1.0	0.0/1.0
3	.50/.25	.50/.50	.25/.50	.25/.50	.25/.75	.25/1.0	0.0/1.0
4	.50/.25	.50/.50	.25/.50	.25/.50	.25/.75	.25/.75	.25/1.0
5	.75/.25	.50/.25	.50/.25	.50/.50	.25/.50	.25/.75	.25/.75
6	.75/.25	.50/.25	.50/.25	.50/.25	.50/.50	.25/.50	.25/.75
Note:	Losses = % Attacker's Factors			Losses = % Defender's Factors			

Table A.3: Enhanced RealLand Strategic Air Bombardment Adjudication

Die Roll	%Attackers Effective
1	50
2	25
3	25
4	25
5	25
6	0

Table A.4: Enhanced RealLand Ground Combat Adjudication

Die Roll	1-3	1-2	1-1	2-1	3-1	4-1	5-1	6-1	10-1
1	.25/.25	0/.25	.25/.25 DR1	.25/.25 DR1	0.0/.25 DR1	.25/.25 DR2	0.0/.25 DR2	.25/.50 DR2	0.0/1.0
2	.25/.25	0/.25	.25/.25 DR1	.25/.25 DR1	0.0/.25 DR1	.25/.25 DR2	0.0/.25 DR2	.25/.50 DR2	0.0/1.0
3	.50/.25	.25/0.0	.25/0.0 DR1	0.0/.25	.25/.25 DR1	0.0/.25 DR1	.25/.25 DR2	0.0/.25 DR2	0.0/1.0
4	.50/0.0	.50/.25	.25/0.0	.25/.25	0.0/.25	.25/.25 DR1	0.0/.25 DR1	.25/.25 DR2	0.0/1.0
5	.75/.25	.50/0.0	.50/.25	.25/0.0	.25/.25	0.0/.25	.25/.25 DR1	0.0/.25 DR1	0.0/1.0
6	.75/.25 AR1	.75/.25	.50/0.0	.50/.25	.25/0.0	.25/.25	0.0/.25	.25/.25 DR1	0.0/1.0
Note:	% Attacker's Factors			% Defender's Factors					

A.2 Model Enhancements

The next steps for this research is to complete the totality of the design and revisit steps within the model development life cycle. I have divided this work into two directions internal dynamics and issue modeling. These are described in great detail.

Internal Dynamics

Enhanced RealLand as described is missing the key element of internal dynamics. In order for the conflict-theory model to be valid, players must feel a personal consequence to their actions. This was also found to be true in Guetzkow's (1963) famous inter-nation simulation. My proposal as a future development within RealLand is to incorporate the social simulation mechanisms for addressing this as articulated in inter-nation simulation.

I propose that players should have an objective to continue office-holding throughout the course of the simulation. To do this, the player must balance domestic and international considerations. The player should allocate its industrial resources, broadly speaking to either the economy for the public good or to security to increase their national power through military means. This allocation should have an impact the goals of increasing national power and staying in office (the classic guns vs. butter). Enhanced RealLand should include the probability of office holding (pOH) as one of the key player variables.

Within Inter-Nation simulation, pOH is a function of a player's decision latitude with his domestic validators and their satisfaction as shown in equation A.1.

$$pOH = a(b - DL)VS_m + c(DL - d) \tag{A.1}$$

where $a = .01$, $b = 11$, $c = .1$ and $d = 1$ (Guetzkow, 1963). These parameters values address the fact that VS_m and DL exist on a 0 to 10 scale. DL is the decision latitude and VS_m is the overall satisfaction of the validators. The decision latitude controls how sensitive the player is to the concerns of its validators. It is a dynamic variable on a 0 to 10 scale that increases or decreases randomly each turn by one point. Players may pressure validators to give more decision latitude at a cost of both satisfaction and economic effectiveness. The concept allows decision-makers to take short term hits to satisfaction to achieve longer term goals.[1]

Overall validator satisfaction is the weighted sum of the validators' economic and security satisfaction. The weight is determined by a society's national character. As shown in equation A.2, societies with greater national character are more accepting of standing military forces and aggressive foreign policies.

$$VS_m = (1 - N_{char})VS_{cs} + N_{char}VS_{ns} \tag{A.2}$$

[1] Validators are the player's domestic power brokers that have influence on elections. In reality, this group is highly diverse across states. However, the only difference between players' societies in Enhanced RealLand is their national character.

In my proposed addition, a society's consumption (CS) is determined by the ratio of wheat to cities, oil to total production, and any production factors invested back into the economy as stimulus or welfare. The minimum consumption is assumed to be 1 wheat per each city and 1 oil per each factor of production. Any additional resources or production contribute to economic satisfaction. Failure to meet the minimum standard for either city or production factor will have an impact even if satisfaction remains in an acceptable range.

$$CS_t = \frac{(\frac{W_t}{C_t} + \frac{O_t}{TP_t})}{2} + \frac{PF_t}{TP_t} \tag{A.3}$$

where t is the turn. The bottom line is that players must feed their people, supply their industry, and may invest directly in their economy at the expense of purchasing further military strength. Additionally, the calculation in equation A.3 provides an incentive for players to maintain a surplus in resources which certainly benefits their populace. Larger, more advanced countries must pay more production factors to see the same results in validators' satisfaction. This dynamic is shown in equation A.4.

$$VS_{CS} = \beta(1 - e^{-CS}) \tag{A.4}$$

where β is a scaling parameter with the value of 10. Consequently, players with a surplus of resources will tend to have a high economic satisfaction. Aggressive players that are growing their military industrial complex must maintain a steady stream of oil.

The economy is only one part of the equation. The second dimension of validators' satisfaction is their sense of security. In Enhanced RealLand, validators consider their player's power ranking, sufficient forces for internal defense of cities, and the likelihood of ground invasion not occurring as shown in equations A.5 and A.6.

$$NS_i = (\frac{p_i}{\sum_{j=1}^{n} p_j} + \frac{\sum_{r=1}^{c} CF_{ri}}{C_i * c_s} + \frac{FB_i}{\sum_{j=1}^{s} FB_j})/3 \tag{A.5}$$

where p_i is the national power of player i, n is the total number of players, s is equal to the number of neighboring states, and c is equal to the number of cities of player i. C_i is the total number of cities in player i and c_s is a factor to represent the force needed to completely secure a city. CF_{ri} is the combat force stationed in city r.

$$VS_{NS} = \beta(1 - e^{-NS}) \tag{A.6}$$

where β is a scaling parameter with the value of 10. The monotonically increasing function yields diminishing marginal results once a moderately high satisfaction is reached. The dynamic appears correct where weak countries with only internal security forces will be dissatisfied while the more powerful countries need only provide token border and internal security forces. In summary, players should be concerned about office-holding and use the various factors they can influence to remain there. This will almost always be an issue for players to wrestle with in strategy development. They are assumed to have the current estimate of validators' satisfaction and decision latitude at the start of their turn.

Now that the internal dynamics have been described, a proposed adjudication approach to the assessment phase follows.

Assessment Phase The objective of this phase is to determine 1) whether the player stays in office and 2) if there is a revolution and to what extent. Within Enhanced RealLand, the validators have an opportunity to determine how well a player fared in that turn. The validators first update their satisfaction based upon the recent events using equations A.4 and A.3. If a decision latitude increase was made during the turn, satisfaction will be degraded as well as the military industrial output for that turn as shown in Equation A.7 and A.8.

$$VS_m = VS_m - (DL_d - DL)/DL * VS_m \tag{A.7}$$

where VS_m is the overall satisfaction and DL_d is the new decision latitude and DL is the original. The larger the increase, the more effect on satisfaction. By equation A.2, a DL is complete latitude. However, this comes with cost.

$$PF = PF - ((DL_d - DL)/DL * (1/Pt) \tag{A.8}$$

where Pt is the frequency of production turns and PF is the total production factors available to the player. Whether the player stays in office is determined by the probability of office retention shown in equation A.9.

$$pOH_m = \sum_i^j pOH/(j - i) \tag{A.9}$$

where j is tenure of that player in office. If the probability of office retention is over a random number than the player states in office. Otherwise, the player agent is removed. A new player takes its place with a different risk tolerance.

Failure to meet a minimum threshold of overall satisfaction will lead to revolution. The probability of a revolution is given in A.10.

$$pR = \frac{gDL + pSR}{h} \tag{A.10}$$

where pSR is the probability of revolutionary success and g and h are controlling parameters with the value of .1 and 2 respectively used in inter-nation simulation. The probability of a revolution being successful depends upon the proportion of forces dedicated to internal security and the number of cities as shown in equation A.11.

$$pSR = 1 - \frac{\sum_{i=1}^{c} CF_i}{c * c_s} \tag{A.11}$$

where c is the number of cities and CF_i is the number of combat forces in city i focusing on internal security. c_s is a factor to represent the force needed to completely secure a city. This is set to a factor of 6 which is the maximum INF units that can be in a city hex. If a revolution is successful, any ground unit with a combat factor of 1 has a chance to join the insurgency. Military units that have not joined the new regime have a chance to desert. Deserters are removed from the board. Desertion is a function of the strength of the unit and distance from the capital. Smaller units are more likely to desert. Units with factor of 5 or more will always be loyal.

$$pDS = 1 - U_s/5 \tag{A.12}$$

A new player is generated to control these forces with the offensive war action to take a production center. A guerrilla unit will be created for the player in each city without a opposing military force. If all cities are controlled by the unpopular regime, a guerrilla unit is created outside the capital city. It will be added to the player activation list immediately after the unpopular player. The unpopular player will have the first chance to crush the active rebellion. When either regime is destroyed, the validators will have a temporary increase in satisfaction.

Issue Modeling

In developing the design of Enhanced RealLand, many issues were considered as critical to realizing the ontological framework. The following issues were considered and documented, but exist at various stages of development. An obvious future direction is to incorporate these advancements and discuss their cumulative impact on the model.

Position Uncertainty Position insecurity is a recurring issue in the simulation as players consider how to achieve certainty in office. Originally when faced with a position insecurity issue, players would always decide that the risk is significant. However, a normally distributed risk tolerance with a mean of .8 and a standard deviation of .05 was introduced to explore the effects of a player's sensitivity to probability of office-holding. If the probability of office-holding is greater than the risk tolerance, the player considers their job safe enough and proceeds to the next issue.

If the players find serious risk in doing nothing, they will explore what can be done and determine the risks to taking action. If the economy is dominant, the lowest risk solutions are trading for additional wheat, oil, or production factors to spend on the economy. If they have stored production factors, players may spend their own production factors in the economy. Alternatively, if it is national security, players can increase forces on the border or in cities to provide more protection. If there are no trading partners and economic satisfaction is dominant, players will look towards their military options. If wheat or oil could be successfully seized this turn leading to a net increase, they will do so if their military power is greater then their neighbor.

After considering the options, players look to satisfice. If they find a solution above their risk tolerance, they will proceed to the next issue. However, the longer position uncertainty has been an issue, the more likely the player will feel that there will be consequences to changing from their committed course of action. Each turn an issue persists increases the likelihood that the player will find risk in executing a new strategy.

If serious risk remains, the player seeks a better solution in the turn. If war and trade will not have an immediate impact, the player is left to consider the option of increasing decision latitude through the use of force. In essence, becoming less subject to validators through coercive means. However this comes with a price. An increase in decision latitude will proportionally decrease validators' satisfaction this turn and reduce economic output for the next production turn. However, if satisfaction slips below revolutionary threshold, a revolution becomes a possibility. Revolutions have a negative impact in general but their conclusion (regardless who wins) will generate a temporary increase in satisfaction from the validators. This is described in the assessment phase in more detail.

If a player finds that the value of increasing the decision latitude is displaced by the probability of a successful revolution by the validators, the player may lose hope and move on to the next issue taking no action. The conflict-theory states that hope for a better solution is a key factor in continued information processing. In Enhanced RealLand, hope is found with a feasible solution to address the issue. A loss of hope is associated with defensive avoidance patterns, such as passing the buck. In any other case, the player may determine whether or not there is sufficient time to search and deliberate. The time is calculated as the weighted pOH of the previous turns in office. The more recent turns will have more of an impact than the previous turns. If the player's average score is less than their risk tolerance, they will become hyper-stressed and take drastic action with military force to increase decision latitude. Otherwise, they will believe there exists sufficient time for choosing the best strategy.

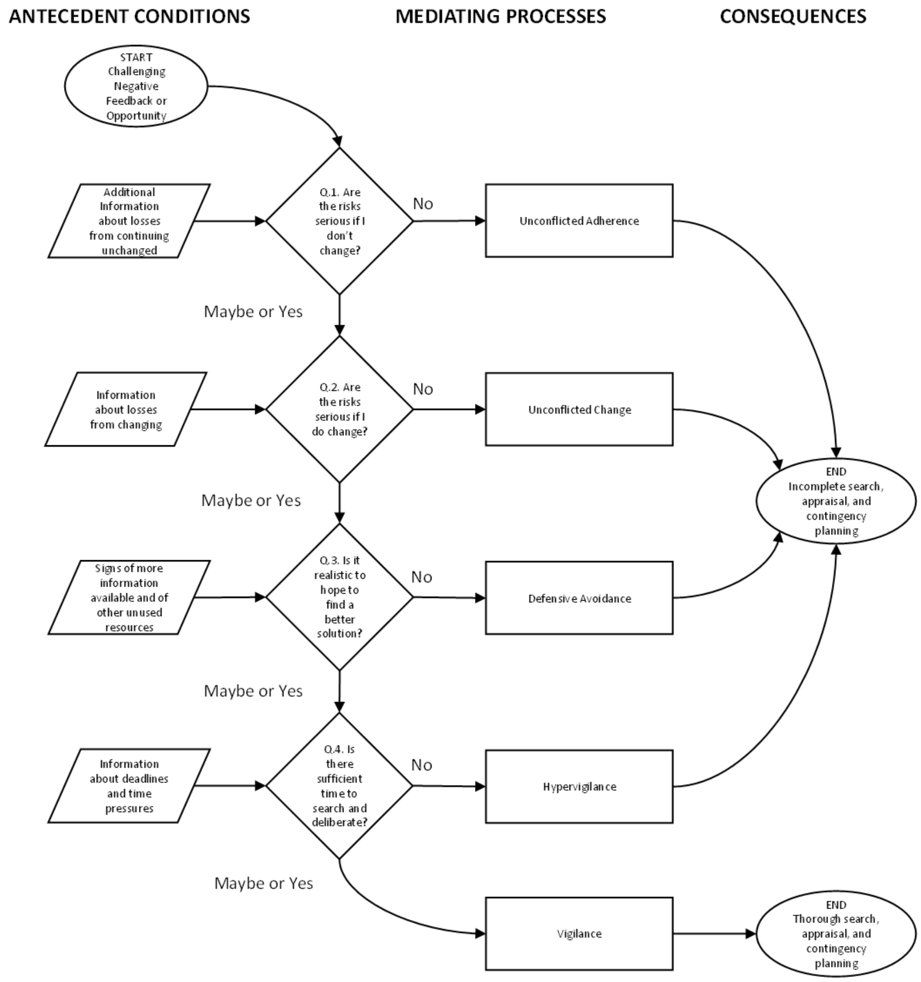

Figure A.1: Conflict-theory model (Janis & Mann, 1977, p.70)

If the answer is yes to the four questions of the conflict-theory model, shown in Figure A.1, the player executes vigilance in information processing and returns to the three options of investment, force re-positioning, war, trade, and increasing the decision latitude. The player finds the best combination of solutions to maintain his position in office while minimizing damage to the country. For instance, war may prove to be the best option but it may take several turns to achieve the objectives of acquiring the wheat and oil. The player may also find that reallocating forces from one border to another will mitigate his plight. In finding a longer term solution, players may increase their decision latitude temporarily in the hopes of resolving the issue over the next several turns rather than risk losing office.

In summary, in responding to position uncertainty, players either dismiss the issue, take the first feasible path to resolution through war or trade, lose hope and do nothing, take rash action to secure their power, or seek to find the best longer term solution. This is the most complicated and dynamic issue that players will face in Enhanced RealLand.

Border Security Players careful monitor the forces on their border and any change will generate an issue. A slight increase will be dismissed by the player as a minor re-positioning that does not affect the balance of power. The player will usually proceed to the next issue unless the player notices a continuous accumulation of forces or there is a sudden spike of forces. If the player has forces to spare, they will send some additional forces in the vicinity of the build up. If the player has no forces to spare, the decisional conflict will increase. If able, the player will have reactionary forces for these contingencies available that do not have a primary mission of border or internal security.

Facing a potential threat on the border, the player will consider its options. If a neighbor is willing to engage in a defensive alliance, or a foreign power is willing to re-position some of their forces, the player has hope for a solution. Otherwise, a player will do nothing. If the player's force ratio on the border is no worse than 1 to 2, the player will believe they still have time to find a solution and optimize against the various options. Otherwise, the player will make alliances and accept foreign forces within their border.

Foreign Forces If foreign forces are detected in a neighboring country, an issue is generated. If the units are transiting on a railroad, the issue will be dismissed as the player believes that they are only passing through the country. If they disembark, the issue becomes one of border security and follows that process combining the foreign forces to those of the hosting player. If there are kinetic engagements between the neighbor and the foreign invader, the player will seek to increase its border strength as a precaution or as a prelude to either an offensive or defensive alliance.

Hungry Powers Players with force projection capabilities will generate issues for other players as they are always a potential threat. The risk of doing nothing is perceived as a measure of both the current forces and the economic strength of the opposing player. A neighboring state with a powerful military that is short on resources is considered to be a significant threat. A weaker player will seek to trade needed resources to the more powerful player, then reinforce the border if trading is not feasible. A more powerful player will only reinforce the border, and then seek a trade if there are no forces to spare. If either of these two options are unavailable, the player's stress increases. If the player is not an immediate neighbor, they will dismiss the issue unless they are trading partners with a potential target of the potentially aggressive state. In this case, their preference is to find another trading partner. If one exists, they will make the change and continue to the next issue. Otherwise, they must look to the defense of their own trading agreement.

At this point, the players are looking for a feasible solution to deter the stronger power from any successful aggressive actions that might interfere with their own interests. If a player has force projection capability, it will consider an alliance with its affected trading partner and forward deploy military forces. If not, it will do nothing. If prepositioning is an option, a player will consider the time and distance to the partner. If not reachable by rail in one turn and a loss of the trade deal would result in wheat or oil insecurity, the player will consider themselves as a declining power and add a power differential issue to the turn. Otherwise, the players will seek to optimize their response.

The Power Differential Within Enhanced RealLand a relative power loss is usually because other players are advancing faster or the country has experienced war. While any power decline will generate an issue, the player will only consider it risky to do nothing if there is either a trend of power decline or a sudden drop. If either is greater than ten percent, the player will consider the risk of doing nothing significant. It now determines the risk of taking action. The risk is determined by the force ratio of the player's allies against the other forces minus the forces allocated to internal defense. If the ratio is at least parity, the player will consider non-military reforms, such as increasing their production centers, building cities, developing further resources, or trades. If the ratio is less than parity, the player's stress will increase to find more alliance partners and build additional military forces. If its force ratio with its allies is so insignificant (less than 1 to 10) compared to the rest of the world, the player will do nothing. If it has hope, in this case meaning that the force ratio is between parity and 1 to 10, the player will return to the initial power differential. If the initial power differential loss was due to an increase in military force by another player, it will become hyper vigilant to increase its military forces. Otherwise, the player will seek to maximize its own national power through economic or military means with minimal effort.

Offensive War. War in Enhanced RealLand is defined as consecutive turns with military operations between one set of players and other. A player engaged in a conflict will continue without committing more forces if they are progressing towards their objective. For example, a possible war action could be defined as [Offensive War, Player A, 2 cities, my border security forces]. The player is seeking two cities from Player A with only its border security forces dedicated to that objective. If the player is gaining territory and the force ratio is the same or better from the last turn, it will perceive little risk in continuing to their objective. However, if it is not gaining territory or its military advantage is deteriorating, it will perceive significant risk in continuing the engagement unchanged.

In a situation where it must change its course of action, the state has an easy option. If sufficient forces are available that are reactionary, not assigned to border security or internal defense, to restore or exceed the previous balance they will add those to the engagement and move to the next issue. If not, the decisional conflict will increase and the player will look for ways for the situation to improve. If the player and their allied partners have more production factors than their opponents, they will believe the situation can get better. If they perceive no hope, they will do no further attacks that turn. If they have hope but available forces cannot make it into the engagement that turn, they will engage in riskier combat. Where ordinarily forces will not engage in ground attacks without at least a 3 to 1 advantage or air strikes without sufficient escort, the players will impel their units to engage in 1:1 or 2:1 attacks. Otherwise, players will seek to optimize the situation. In this case, players may seek additional alliances, pull forces from the border of other states, or from internal security

Alliances A standing alliance action is structured in the following fashion [Defensive Alliance, Player B, Player C, Open Border, verified?]. Players may provide incentives for alliances or may just express a mutual concern. Another example could be [Preposition with Defensive Alliance, Player B, Player C, 1 PF, 20 CF] where the player is willing to support deployed combat forces (up to 20 factors) by offering a production factor. Alternatively, those same examples could be offensive alliances. In this case, they allocate forces for attack not defense. The other kinds of alliances are ad hoc pleas for help where players submit a [Help, all players, player C, nothing,50 CF]. Players post there alliance requests globally. Accepting an alliance is done during each player's turn. As players review the issues, they may need to make alliance requests. If other players have already made the same request of them, the alliance is immediately accepted and marked verified. Otherwise, after clearing all their issues, the player appraises alliance requests as an opportunity to increase or reinforce their national power.

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Curriculum Vitae

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