STRATEGIC OFFENSE, DEFENSE AND ARMS CONTROL

FINAL REPORT

A STUDY FOR
THE DEFENSE THREAT REDUCTION AGENCY
ADVANCED SYSTEMS AND CONCEPTS OFFICE

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SPARTA, Inc. / DFI INTERNATIONAL

SPONSOR: Defense Threat Reduction Agency. Dr. Jay Davis, Director

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BACKGROUND: The Defense Threat Reduction Agency (DTRA) was founded in 1998 to integrate and focus the capabilities of the Department of Defense (DoD) that address the weapons of mass destruction threat. To assist the Agency in its primary mission, the Advanced Systems and Concepts Office (ASCO) develops and maintains and evolving analytical vision of necessary and sufficient capabilities to protect United States and Allied forces and citizens from WMD attack. ASCO is also charged by DoD and by the U.S. government generally to identify gaps in these capabilities and initiate programs to fill them. It also provides support to the Threat Reduction Advisory Committee (TRAC), and its Panels, with timely, high quality research.

ASCO ANALYTICAL SUPPORT: SPARTA, Inc. and DFI International provide analytical support to DTRA through a series of projects on chemical, biological, and nuclear weapons issues. This work was performed for DTRA under contract DTRA01-00-D-0001, Delivery Order 0003.

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Strategic Offense, Defense and Arms Control
Final Report

Task 2 – An Overview of Model Definitions and Dynamics

Introduction

The evolving strategic nuclear environment requires US defense planners to grapple with increasingly complex relationships as compared to the bipolar, offense-dominated era of the past fifty years. Foremost among considerations in this emerging world are the potential reduction of both US and Russian strategic offensive forces (SOF) to low numbers, the resulting increased importance and probable growth of Chinese SOF, and the potential introduction of strategic defensive forces (SDF) into the arsenals of one or more of these states. These changes will lead to the development of complex, three-way strategic interactions between the US, Russia, and China, featuring asymmetrical combinations of SOF and SDF. Although improvement in the US-Russian political relationship has reduced the likelihood of nuclear conflict, the increasing complexity of the strategic environment will alter national security decisionmakers' perceptions of strategic vulnerability and the need to adjust nuclear force postures, strategies, and diplomatic policies. In particular, these decisionmakers must now consider the triangular dynamic when assessing the potential threats confronting them and their own options to provide for national security. Strategic options to consider in this regard include alliances, defenses, changes in offensive force structure or posture, and arms control measures.

These new challenges intensify the complexities and challenges that the US and the Soviet Union never fully came to terms with during the Cold War. Such problems included the possibility of technological breakout – the risk that one party might achieve a sudden unexpected advantage over the other because of a technological innovation. Another issue concerned perception of intent: one strategic actor's perception of another's worldview (e.g., its revisionist or status quo objectives) historically has had a significant impact on the degree of risk perceived. Similarly, nuclear strategy and doctrine were subject to extensive debate in the US throughout the Cold War. In the extreme cases, some strategists and one president argued that deterrence could be achieved through the assured survivability of only a handful of nuclear warheads to be used to retaliate for a first strike.[1] On the other side of the argument were those analysts who argued that deterrence could only be achieved through an outright superiority in nuclear warheads, thereby allowing the US to prevail in an extended nuclear conflict.[2] Taken together, these old and new complexities present today's US defense planners with significant challenges.

This report provides the analytical foundation for a model that enables planners to explore the likely interaction effects among a wide range of factors influencing strategic nuclear relationships and national security. The model facilitates the assessment of emerging strategic dynamics by simulating the deployment of defenses, adoption of arms

[1] In 1979, responding to criticism about the size of the US nuclear arsenal, President Jimmy Carter commented that "just one of our relatively invulnerable…[missile] submarines – less than two percent of our total nuclear force of submarines, aircraft, and landbased missiles – carries enough warheads to destroy every large and medium-sized city in the Soviet Union. Our deterrent is overwhelming" (see Fritjof Capra, *The Turning Point: Science, Society, and the Rising Culture* (New York: Simon and Schuster, 1982), p.240). Although more an offhand comment than an argument for official administration policy, Carter expressed such sentiments at times. His views reflect well the position that limited forces can achieve deterrence.

control and threat reduction measures, alterations in offensive force structure and posture, integration of new technologies, changes in strategy and doctrine, and the formation of alliances. The ultimate aim of this effort is to provide US decisionmakers with a resource to assess trade-offs among the range of options available to them in response to challenges posed by strategic competition and cooperation through 2020.[3]

This report first summarizes previous research on this subject noting substantive findings, methodological issues, and shortcomings of that work. Then the report lays out a conceptualization for an actor-based model of three-way strategic interaction. The primary driver for strategic interaction is the decision calculus performed by state actors including threat perception, option formulation, decision criteria, and policy choice. The discussion defines and specifies the key variables and terms used in the formulation of the model. The report concludes with a discussion on how a model excursion ends, its explicit outputs, as well as the range of pre-set scenarios available to the user.

Previous Research

In developing the concepts, definitions, and dynamics of the model, the project team reviewed previous analyses and models of strategic stability.[4] Four main themes emerge from the literature. First, the maintenance of strategic stability against nuclear attack requires an *effective* and *stable* deterrent, although the definition of a stable

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[2] For example, see Colin S. Gray, "Nuclear Strategy: The Case for a Theory of Victory," *International Security* Vol.4, No.1 (Summer 1979), pp.54-87.

[3] One option not available to the actors is the launching of a first strike. As discussed in greater detail later in the text, the initiation of nuclear conflict would likely be caused by extraordinary political factors that are not considered within this model. Each player, however, most routinely assess the effects of a first strike to limit its vulnerability.

deterrent varies by state. Second, the optimal strategic stability environment results from states' possessing minimal *offensive* forces for mutual deterrence (highly survivable delivery systems with small numbers of warheads). Third, advances in technology can and do dramatically affect strategic stability. Lastly, an actor's perceptions of its competitors' intentions and vital interests have a critical effect on its perceptions of the threat and the efficacy of nuclear deterrence.

Moving beyond these broad themes, researchers, especially modelers, can produce significantly different specific findings largely as a result of how they address four key methodological issues:

- guiding assumptions,
- specification of the dependent variable,
- range of independent variables included, and
- model complexity.

Variations in the assumptions that undergird any model or argument obviously have profound implications. The measurement of the dependent variable differs somewhat among researchers, despite "strategic stability" being the overarching goal. The most common measure of stability is some variant of first-strike advantages.[5] Whatever a researcher's definition of strategic stability is, the choice of which strategic factors to employ as independent variables affects the outcome enormously. All models

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[4] For the literature review and bibliography of these works, see the Appendix. The literature review includes all three broad approaches to understanding strategic stability: deductive arguments, inductive arguments, and deductive models.

[5] Even if all parties possess survivable nuclear forces and thus significant second-strike capabilities, if a state would fare far better by striking first rather than second, then pressure may exist to do so in a crisis. The key question becomes how much better off would a state be in terms of damage suffered by striking first?

include the absolute number of warheads available to both an attacker and defender, but other independent variables employed at times include warhead survivability/vulnerability, warhead lethality, retaliatory terms of use (launch policies and targeting criteria) and, if including defenses, the absolute number of interceptors, their effectiveness, and firing doctrine. Models differ in complexity largely on the basis of the interaction among variables, as well as the level of detail used to characterize each one.

The above substantive and methodological perspectives have informed the project team's model design and construction. With regard to the current state of play, the study team came to the following conclusions:

- Threat reduction generally appears not to have been modeled as an explicit component of evaluating strategic stability. Some efforts to consider aspects, such as how force posture affects a situation, have been calculated but researchers predominantly have assessed offense-offense and offense-defense tradeoffs.

- The vast majority of work evaluates dyads (principally the US versus the USSR), while multipolar modeling is in its infancy. The reduction of US and Russian arsenals, the probable growth of Chinese nuclear forces, and the horizontal proliferation of nuclear weapons suggest that in the future, multipolar models will be of increasing necessity.

- Technological and political conditions are increasingly dynamic, thus requiring more sophisticated models. Moreover, actors in a deterrent relationship may possess contrasting strategic cultures, which can significantly affect leaders' perceptions, calculations, and behaviors. Such considerations typify the need for greater sophistication than was required during the Cold War.

These factors and conditions, representative of the evolving strategic environment, must be included in models if they are to prove useful tools for US defense planners. Recognition of these requirements shaped the subsequent effort by the project team to develop a model of strategic interaction that includes the potential deployment of defenses, arms control and threat reduction measures, shifts in offensive force structure and posture, technological change, alliances between two of the three players, and perceptions of the threat. Although other models have incorporated one or several of these variables, none has tackled all of them.

Conceptualization of an Actor-Based Model of Strategic Interaction

The project team has determined that the best approach to achieving multi-party dynamism is through an actor-based model of strategic interaction. The central component of the model is a nested set of parallel decisions by three actors (Blue, Green, and Red).[6] Each player possesses a set of decision rules and is confronted with a set of exogenous factors (e.g., the force postures and preferences of the other players). The outcomes of the three players' decisions – the conclusion of the model "round" – represent the preconditions for the subsequent rounds of interaction. Each round simulates one year, although a user may substitute a longer length of time up to twenty years. This longer timeframe allows the model to capture significant alterations to the force structure in a limited number of turns and facilitates readily studying the effects of these changes, albeit with a greatly reduced resolution of player interaction.

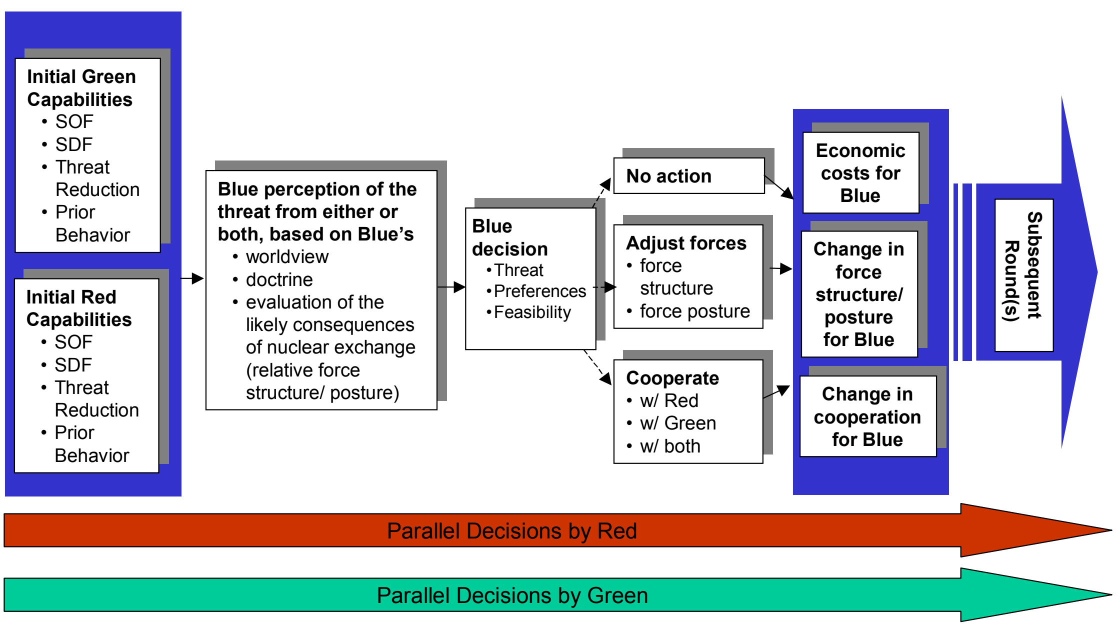
Figure 1 presents a graphical depiction of the model's operation for a single round with a focus on one actor's (Blue's) decisionmaking. The model has each player reaching

[6] The three players represent the United States (Blue), China (Green), and Russia (Red).

a decision by going through a series of steps: perception of the threat, determination of possible courses of action, application of decision criteria to evaluate these courses of action, and selection of a preferred action. The outcome arising from the policy adopted by the actor as well as simultaneous choices by the other two players constitutes the end of a turn.

The remainder of this section examines each of the above components, providing specific details and definitions. The steps are the same for all three players, although specification of variables differs where appropriate because of divergent capabilities, resources, and preferences.

FIGURE 1: DECISION PROCESS



Determination of Threat Perception

An actor's first step is to assess its vulnerability to the other two states. At the beginning of each turn, a player would possess objective knowledge of the other players' existing strategic offensive and defensive forces, systems being built and dismantled, mutual threat reduction measures, and prior strategic behavior.[7] A player's perception of the threat from either or both of the other actors results from three general factors: its *worldview*, its *strategic doctrine*, and an evaluation of the *likely consequences of a nuclear exchange* given relative force structure and force posture. The inclusion of *worldview* and *strategic doctrine* allows the model to capture differences in political perspective and strategic culture among the various states. Otherwise, threat perception would be evaluated as a purely numerical calculation devoid of real-world influences.

<u>*Worldview*</u>

An actor's *worldview* with respect to the other players largely emanates from the types and degrees of risk that most concern it. The model includes three types of risk that influence a player's worldview: perceived risk of a competing alliance, tolerance of risk of accidents, and perceived risk of technological breakout. First, if a player believes the other players might act in concert, then it must size its forces to deter both adversaries, rather than being able to size its force just to deter the larger of the two opponents. Second, what type of risk concerns a particular player more – risk of preemption or risk of accidents? The study team concluded that actors must place one of these concerns before the other. Any player that is more concerned about being preempted than about the risk of accidental nuclear war will be more inclined to put a large portion of its forces on a Launch under Attack (LUA) posture vice rideout such an attack. If a player is more concerned with accidents than the risk of preemption, it will be less inclined to put forces on LUA status. Third, to what degree does the player perceive a risk that one or both of the other players would gain a sudden advantage in capability due to technological breakout? Any actor that perceives a high risk of technology breakout must make relatively conservative calculations of its own capabilities when gauging stability.

Strategic Doctrine

Closely related to its *worldview* is an actor's *strategic or nuclear doctrine*. That is, what are an actor's perceived requirements for achieving and assuring deterrence? Although significant variations may exist among particular strategic doctrines, three basic types have been selected as a baseline for model development: minimum deterrence, extended deterrence, and warfighting deterrence. Using Blue's requirements as an example, *minimal deterrence* requires forces that allow it to retain at least 200 warheads *after* an attack on Blue by one of the other players.[8] *Extended deterrence* requires sufficient forces that allow Blue to strike first effectively against another player, absorb a retaliatory strike, and still retain at least 200 warheads to successfully deter subsequent attacks or a response from the other player. *Warfighting deterrence* requires forces sufficient for Blue to survive a first strike, respond proportionately, and still retain

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[7] For the purposes of model simplification, players have perfect information exchange. There is no misperception of the physical activities and arsenals of the various players.

[8] The project team selected 200 warheads as the minimum deterrence level for Blue because this size arsenal would be sufficient for destroy most of the population and industry in Russia or China. US officials since the 1960s have annunciated such criteria as the level needed to ensure deterrence. Although

at least 200 warheads to deter subsequent attacks. For other players, the numerical warhead requirements in all three doctrinal types are likely to be different.[9] Users will also be able to evaluate alternative definitions and doctrines of their own specification.

<u>Potential Effects of Nuclear Exchange</u>

In each round, every actor evaluates its vulnerability by calculating the potential effects of nuclear exchanges, given its existing force structure, force posture, doctrine, and risk requirements as well as the corresponding factors for the other players. Each player strives for "security," defined as when its number of survivable warheads meets or exceeds its threshold level for deterrence. Thus, each turn, players judge each opponent's capabilities (potential arriving warheads) against their own deterrence thresholds for *n* turns, where *n* represents the longest period each player will tolerate insecurity. Figure 2 depicts the equations for each of the baseline doctrines.

175 or 225 warheads would have approximately the same effects, 200 was chosen as a representative number below which US officials would likely not accept barring a radical change in strategic thinking.

[9] For example, China is generally viewed as possessing a minimum deterrence posture that relies on the survivability of only a handful of warheads.

FIGURE 2: THREE TYPES OF STRATEGIC DOCTRINE

Security for minimal deterrence actors exists when:

[# of warheads] – [# destroyed] – [# surviving weapons] ≥ [threshold level]
to start by attack destroyed by defenses

Security for extended deterrence actors exists when:

[# of warheads] – [# warheads] – [# destroyed] – [# surviving weapons] ≥ [threshold]
to start used in attack by response destroyed by defenses level

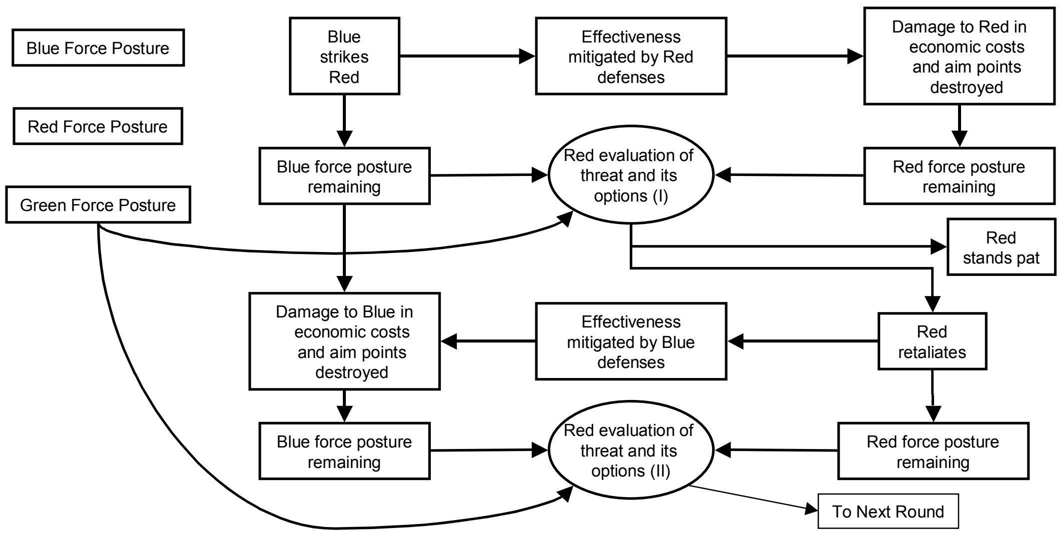
Security for warfighting deterrence actors exists when:

[# of warheads] – [# destroyed] – [# warheads] – [# surviving weapons] ≥ [threshold]
to start by attack for response destroyed by defenses level

In making these calculations, as noted previously, the model assumes transparency for players' current force structure as well as production and dismantlement pipelines.[10] A player, however, is not aware of other players' simultaneous actions until the completion of a particular round as decisions are being made in parallel. Figure 3 depicts an example threat calculus by Red.

[10] For simplicity, the model also assumes that players will opt for the maximum levels of production permitted by industrial-base constraints.

FIGURE 3: EXAMPLE OF AN ACTOR'S CALCULUS OF CONSEQUENCES



In this draft calculus, Blue preempts Red and Green does not participate. If the outcome is unacceptable for Red, Red must take steps to reduce its vulnerability. If Red finds itself unduly vulnerable in this calculus, it must respond by changing its force capabilities or other measures.

Potential Courses of Action

Possessing a threat perception of the current situation as well as future trends, a player has three basic options in any given round: *no action, unilateral force adjustments,* or *cooperation*. A player can always choose to do nothing, even if it regards the status quo as perpetuating insecurity, because alternative actions may be judged to be worse. An actor may pursue unilateral force adjustments in a variety of ways. It could either increase offensive force structure or improve the survivability of the existing offensive force through placing a higher number of strategic systems on alert or adopting a LUA posture (but not increasing target hardness). Also, a state could deploy strategic defenses or increase the number of interceptors. A player can also pursue cooperation in more than one fashion. Cooperation may take the form of an alliance with either of the other players. An actor also may engage in cooperative threat reduction (e.g. arms control) with one or both of the other players, decreasing the size of its force structure.

Even though each player must routinely contemplate the effects of a first strike, as noted above, the model does not permit a player to initiate nuclear conflict. Instead such calculations allow a player to determine its vulnerability and the value of force adjustments. The model excludes initiating nuclear conflict as a course of action because a state would not engage in a preemptive strike, even if it possessed a clear advantage, except in the direst of circumstances, linked to concerns and events that cannot be easily modeled. Instead when calculations show a severe vulnerability between arsenals, the disadvantaged state will work to eliminate the discrepancy through changes in force structure, posture, or the formation of an alliance.

Adjustments to force structure and posture are modeled in discrete increments. The use of increments simulates the constraints of defense-industrial base throughput capacity. For example, when increasing strategic offensive force structure, a player will first choose the most readily available option – perhaps to upload Multiple Independently-Targetable Reentry Vehicle (MIRV) missiles – and then, if necessary, take on the more resource-demanding challenge of increasing the number of delivery systems according to desired ratios.[11] When increasing strategic offensive force posture, a player will place its strategic offensive forces on a Launch under Attack posture. When decreasing strategic offensive force posture, a player will take its SOF off a LUA posture. When cutting or limiting SOF, a player will first download warheads from MIRVed missiles, and then, if necessary, reduce delivery systems. When increasing or decreasing its strategic defensive forces, a player will increase or decrease the number of interceptors (which are limited to one warhead per interceptor).[12]

Decision Criteria for Option Evaluation

When evaluating the merit of an option, a player considers its *feasibility,* its *ability to satisfy security requirements*, and its *compatibility with behavioral preferences*. In other words, can it be done? How well does it work? How well does it fit with the player's strategic "personality"? Having already outlined the parameters for calculating security requirements, this section explains the *feasibility constraints* and *behavioral preferences* employed in the model.

Feasibility

In order to achieve a degree of verisimilitude not found in other strategic interaction models, the study team developed a number of *feasibility* constraints to serve as the context for player decisions and subsequent actions. In particular, *feasibility constraints* affect the size and shape of the force increments available to each player. There are four feasibility factors: economic costs, production constraints, risk tolerance, and willingness of others to cooperate. Financial resource limits constrain player actions. Some actions – even if they address the perceived threat and fit behavioral preferences –

[11] A player might not be able to build and deploy MIRVs, limiting its force options to increasing the number of single warhead missiles. For example, Green lacks the ability to MIRV until 2005 in the model's default settings. This restriction reflects existing technological limits in China.

[12] A player could also increase defense force effectiveness by enhancing interceptor P_k, but the model assumes players have chosen maximum available P_k, making improvements only after technological breakthroughs.

are not affordable. Thus, these constraints are oriented towards preventing an actor from generating forces continuously as well as expanding force size *ad infinitum*.

The model employs two economic (cost) thresholds for defense expenditures. A player has a *normal* limit (defined as a percentage of its GDP) that it will not exceed when feeling secure. A player also has an *absolute* limit (again defined as a percentage of its GDP, but higher) beyond which it cannot spend under any circumstances. Moreover, to account for non-strategic military requirements, a player cannot allocate more than 30% of its defense expenditures on SOF, SDF, and threat reduction activities combined.

Individual users may input their own customized data, but default economic baselines exist in accordance with present US, Russian, and Chinese realities. For a 2001 baseline, each player has a GDP level: Blue ($9 trillion), Green ($1 trillion), and Red ($400 billion).[13] Normal maximums are derived from early post-Cold War expenditure levels: Blue (4.5% of GDP), Green (4.5%), and Red (7%). Absolute maximums are derived from peak Cold War expenditure levels: Blue (10% of GDP), Green (11%), and Red (16%).[14] Although these thresholds do not change from turn to turn, each player's GDP will change at a specified rate of growth. The default setting has Blue GDP rising 3% each turn, Green GDP rising 5% for ten turns and then rising 3% for each turn, and Red GDP staying flat for ten turns and then rising 2% each turn.[15]

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[13] Baseline GDPs for 2001 are based on 1999 GDP figures. The project team derived these economic factors after consulting an array of sources (the US Department of State, the US Bureau of the Census, International Institute for Strategic Studies, and the World Bank).

[14] Lacking a period of absolute maximum spending by China during the Cold War due to its secondary role, the absolute maximum for Green is based on rough proportionality with Blue and Red normal-to-absolute ratios.

[15] GDP changes for Blue, Green, and Red are based on approximations of projected future economic growth for the US, China, and Russia respectively.

Regardless of a player's economic resources, its industrial base and technological capabilities also constrain its ability to alter force structure. In recognition of industrial base limits, a player can build only up to a maximum number of units during a single turn. The specification of these units is by player and type of weapon system (e.g., Green SSBNs). Each player has a baseline maximum units/turns for construction (e.g., one Green SSBN can enter construction per turn and it takes X number of turns to build). Each turn after building at the maximum level, a player's industrial base increases by a factor of 1.5 (e.g., 1, 1.5, 2.25, etc).[16] By contrast when not building at or near the maximum level, a player's industrial base decreases by the same rate back towards the baseline (e.g. 2.25, 1.5, 1).

A player's technological limitations also may significantly constrain the range of available force structure alterations. The model employs specific probability of kill (P_k) figures for each Blue, Red, and Green weapon system against specific types of targets. The model maintains constant P_k measures for all players throughout a run, with one exception – the formation of an alliance. In alliances, the P_k of the less advanced alliance partner rises halfway to the level of the more advanced alliance partner (for defenses as well as offenses, if both members of the alliance have defenses). Also, model users have the option to boost SOF/SDF P_k values for one or more actors. The model provides all players with MIRV capability by 2005 (as noted above, Green lacks this capability until that point). Additionally, Red and Green are limited in the type of strategic defenses they can unilaterally deploy. Red's SDF options are limited to Moscow-type ABM systems with correspondingly lower P_ks (i.e., nuclear-armed interceptors instead of hit-to-kill

[16] Over time, the real constraint is likely to be available economic resources rather than a limited industrial

kinetic defenses).[17] Green cannot have defenses prior to 2020, then only Moscow-type ABM systems.

A final dimension of feasibility constraints is the willingness of at least one of the other two players to be partners. An actor cannot adopt a cooperation-based course of action unless at least one of the other two players also seeks such cooperation. Additionally, some constraints exist on the types of agreements available to players. Increments of threat reduction are feasible only to the least common denominator (e.g., all parties agree to cut particular systems). Alliances are only possible between players that perceive themselves to be insecure, reflecting the non-ideological conditions of the post-Cold War world.

Behavioral Preferences

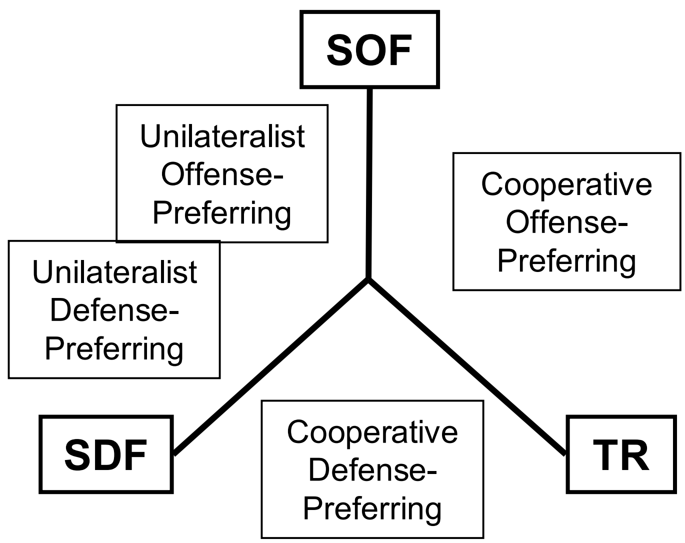
The study team additionally sought to evaluate the effects that *strategic personalities* might have on strategic interactions. For example, the study team sought to create the basis for measuring whether stable outcomes can be achieved between a player that prefers defenses and other players that prefer offenses. Similarly, personality elements should recreate the likely dynamics that occur when some players prefer cooperation and others unilateralist behavior. As considered here, strategic personalities are the product of geographic, geopolitical, cultural, historical, and economic factors. *Ceteris paribus*, these factors influence whether a state would prefer offenses or defenses as well as cooperation versus unilateralism. From these two axes, four personality

base. Thus, no absolute limit exists for an industrial base. Increasing the industrial base by a factor of 1.5 tracks with early Cold War figures (1950s and 1960s) reflecting an intense rivalry.

[17] In attributing P_ks to defense, the default setting for both types of systems is the same. However, a properly functioning hit-to-kill system should provide a higher P_k.

archetypes can be identified: (1) Cooperative, Offense-Preferring player, (2) Cooperative, Defense-Preferring player, (3) Unilateralist, Offense-Preferring player, and (4) Unilateralist, Defense-Preferring player. Depending on user inputs, Blue, Green, and Red will fall into one of these preference categories. Player-types do not change throughout the course of the model run. Figure 4 below shows the relative perspectives of these four strategic personalities:

FIGURE 4: PLAYER PERSONALITY TYPES



Each player-type creates a predisposition towards particular actions. The Cooperative, Offense-Preferring player favors SOF and threat reduction over SDF as well as cooperation, when feasible, over unilateral actions. The Cooperative, Defense-Preferring player favors SDF and threat reduction over SOF. It also prefers cooperation, when feasible, to unilateral actions. The Unilateralist, Offensive-Preferring player favors SOF over SDF and threat reduction. Such a player has strong unilateralist tendencies, making it highly reluctant to cooperate. The Unilateralist, Defense-Preferring player favors SDF over SOF and threat reduction. Such a player also has strong unilateralist tendencies, making it highly reluctant to cooperate.

Each player-type also possesses a declining order of preference for the types of actions favored by the other three player-types.[18] When feasibility constraints prevent a player from acting within its normal preferences, it will therefore resort to alternatives in a fashion that deviates as little as possible from the usual parameters of its strategic personality. Greater dissonance exists between offenses and defenses than unilateralism and cooperation in terms of behavioral preferences; at least this model assumes such a view. The role of these player-types and their declining order of preferences in the model are explained further in the next section.

Choosing a Course of Action

The model simulates the decisionmaking process for each player using the criteria given above. In general, players will analyze all feasible options before choosing an action. This analysis consists of two parts. First, the player identifies which options are consistent with its preferences. For example, a Cooperative, Offense-Preferring player would regard the primary options available as altering SOF posture, adjusting SOF force

[18] In defining a player's declining order of preferences, greater weight is given to the offense-defense distinction than the cooperative-unilateral distinction. Thus, for example, the declining order of preference for a Cooperative, Offense-Preferring player would be (1) Cooperative, Offense-Preferring, (2) Unilateralist, Offense-Preferring, (3) Cooperative, Defense-Preferring, and (4) Unilateralist, Defense-Preferring.

structure, engaging in mutual threat reduction, and forming alliances.[19] All four of these actions fall within its preference-type.

Second, a player assesses which options will satisfy its security requirement. For a minimal deterrence actor, for instance, the qualifying options are limited to those that can ensure that the number of warheads capable of penetrating adversarial defenses and arriving on the enemy, even after suffering a first strike, is at least as great as what decisionmakers regard as necessary for deterrence. It is important to note that both preferred and non-preferred options may satisfy a state's security requirement.

Players will seek a course of action that satisfies their security requirements (acceptable choices) in a way that is most consistent with their behavioral preferences. Figure 5 below describes the prioritization scheme employed by players in selecting a course of action. The subsequent paragraph and Figure 6 provide an example of this decision hierarchy to help illustrate the process.

[19] The primary options available for the other three player types are: Unilateralist, Offense-Preferring (alter SOF alert level or force structure); Cooperative, Defense-Preferring (alter SOF alert, SDF buildup, mutual threat reduction, and alliance formation); and Unilateralist, Defense-Preferring (alter SOF alert or SDF buildup).

FIGURE 5: PLAYER DECISION HIERARCHY

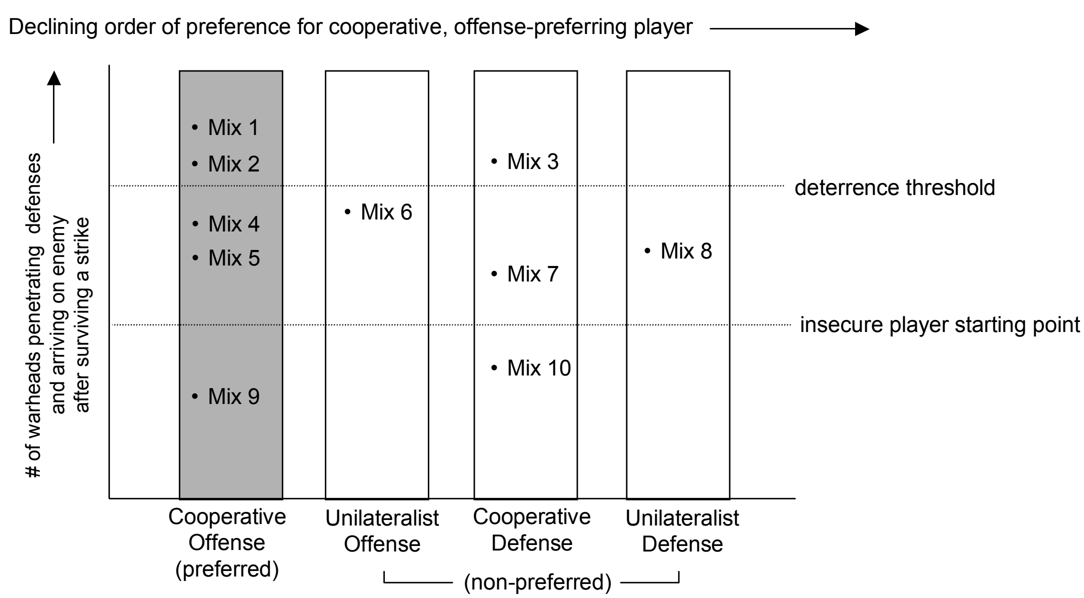
A course of action includes various options, depending on which are feasible for each player

1. A player first looks for actions that will satisfy its security requirements by following a path *that is consistent with its preferences*
2. If there are no acceptable courses of action available within its preferences, a unilateralist player will add treaty defection to its options and evaluate courses of action again
3. If there are still no acceptable courses of action, a player will search for one outside of its preferences (in decreasing order of preference)
4. If a cooperative player evaluating unilateralist courses of action cannot find an acceptable course of action, it will add treaty defection to its options and evaluate courses of action again*
5. If there are still no acceptable courses of action, a player will choose a course of action consistent with its preferences that is closest to acceptable *without worsening its position*
6. If there are still no acceptable courses of action, a player will search for one outside of its preferences (in decreasing order of preference)
7. If there is no course of action that does not worsen the player's position, it will choose a course of action consistent with its preferences that is closest to acceptable
8. If there are no feasible courses of action consistent with the player's position, it will search for one that is closest to acceptable outside of its preferences (in decreasing order of preference)
9. No action

* Although not in the model due to its complexity, a cooperative actor probably would seek to modify the treaty before outright defection.

Figure 6 below provides an example of this decisionmaking process for a Cooperative, Offense-Preferring player that is currently insecure. The player prefers to choose Mix 1 or Mix 2, whichever is most affordable because they satisfy its security requirement consistent with its preferences. The mixes represent potential courses of action. If neither 1 nor 2 is available, the player will choose the first non-preferred course of action that satisfies its deterrence threshold (i.e., meets its security requirement), Mix 3. If Mix 3 is unavailable, the player will choose, in declining order of preference, the course within its preference category that comes closest to satisfying its deterrence threshold (Mix 4). If 4 (and then 5) are unavailable, the player will choose the non-preferred course that comes closest to satisfying its deterrence threshold (Mix 6). If 6 is unavailable, the player will choose by declining order of preference, Mix 7, then Mix 8. If 7 and 8 are unavailable, the player will choose the course of action within its preferences that comes closest to satisfying its deterrence threshold (Mix 9). If 9 is unavailable, the player will choose the course of action that comes closest to satisfying its deterrence threshold, by declining order of preference (Mix 10). If absolutely no course of action is available, the player will not act.

FIGURE 6: EXAMPLE OPTION RANKING



Outcomes from Implementing Player Decisions

With all three players making decisions in parallel each turn, the multiple-round model simulates the dynamics of strategic interactions over time. An excursion will continue running until reaching a pre-defined end-state. The optimal end-state is stability

– an environment that occurs if all three actors possess net offensive capabilities consistent with their deterrence doctrine and simultaneously choose the option of no further action. Sub-optimal end-states are also possible. First, one or more actors could lack the ability to acquire a secure deterrent force, given feasibility thresholds. The excursion ends when an actor's technical or economic limitations prevent further unilateral action, while other players refuse to engage in cooperative behavior. A second type of sub-optimal end-state results if the model fails to reach stability after a large number of turns. In this case, incentives for arms racing persist for at least two players.

Upon reaching an end-state, the model provides the user a variety of outputs to evaluate player actions and dynamic effects. First, the model denotes the actions undertaken by all three players in the game: the forces and postures altered by turn, the threat reduction measures adopted by turn, and the number of rounds required to complete the game. The model also provides the economic costs of these actions in terms of investment as well as operations and maintenance. Finally, the model compares players' end-states with their starting points in terms of security, remaining force structure, and remaining force posture.

Conclusion

This strategic interaction model should enhance the ability of US defense planners to consider the trade-offs and consequences for particular courses of action, including the potential reactions of Russian and Chinese strategic decisionmakers. The inclusion of a third actor (Green, representing China) as well as a third type of activity (threat reduction in addition to SOF and SDF) allows this model to capture the evolving strategic environment more accurately than existing tools permit. In an effort to maximize the model's value to defense planners, the vast majority of the variables can be adjusted within feasible ranges to specifications determined by the user.

The model also includes several pre-formulated scenarios (constellations of scored variables that represent a plausible strategic environment) that can be run without modifying the code. These scenarios simplify the use of the model, while offering the more sophisticated user a range of baselines from which to deviate. The potential scenarios were selected for their plausibility and/or interest as strategic futures:

- baseline – years 2001, 2005 and 2020
- significant technological change for a player or players – increase in offense and/or defense P_ks,
- significant change in the arms control regime – defection of a player, fundamental change of existing regime, or creation of new regime
- significant change in warning time for players,
- formal military alliance between two players,
- emergence of a revisionist, highly risk-acceptant player, and
- significant domestic political pressure on player(s) to be belligerent and/or militarily vigilant.

Users can also save the input specifications from their own scenarios, along with the results, to assist in subsequent excursions. Users should regard this document as the conceptual and definitional framework for the model. Before actually using the model, they should examine the attached operation manual.

Strategic Offense, Defense and Arms Control
Final Report

Task 3 – Mathematical Model

Exchange Model

Model Fundamentals
Actor behavior is driven by expected force performance. The following force performance measures are based on the number of warheads and their destructive capability:

- Raw Force Totals
- Yield
- Equivalent Megatonnage
- Counter Military Potential
- Area Destroyed

These force performance measures combine to produce the following measures of effectiveness:

- Guaranteed Retaliatory Capability
- Averted Losses
- Balance of Power

Model Measures of Performance
Force performance is measured in five ways:

- Total number of effective warheads (Raw force totals)
- Total effective force yield
- Total effective equivalent megatonnage
    - Yield(2/3)
- Total effective counter military potential
    - $\text{Yield}^{(2/3)}$ / Accuracy^2
- Number of Standard Urban Areas destroyed
    - ($\text{Yield}^{(2/3)}$ / 58) / 200
    - 1 EMT generates a 2-3 psi shock wave over the equivalent area of 58 sq km
    - 200 sq km defines a "Standard Urban Area" - equivalent to New York metropolitan area

Note that all of the performance measures are based on <u>number of warheads</u>.

Model Measures of Effectiveness
<u>Guaranteed Retaliatory Capability</u> is defined as the effective capability of those forces surviving a 1st strike. This is measured against total forces, or those available for non-SOF targets. This is a key measure of deterrence and stability; a standard quantified level

is the “McNamara” number of 400 EMT. Averted Losses is defined as the difference between striking first, and waiting to be struck. This is measured in terms of enemy capability to inflict damage on friendly side, which is measured as total damage, or damage against non-SOF targets. This is a key measure of crisis stability. Balance measures equivalence of forces, in terms of total forces, or those available for non-SOF targets. This provides insights into perceptions of advantage, and is a basic stability measure.

Underlying Model Structure

The model can be reduced to very simple terms. For each weapon type, it calculates capability as

$$w_e = w_a \times p_s \times p_l \times p_p \times p_d$$

where:

w_e= the effective number of weapons for a given weapon type
w_a = the number of warheads of a given weapon type
p_s = the probability of survival
p_l = the probability of successful launch
p_p = the probability of penetrating through defenses
p_d = the probability of successful detonation

w_e is summed for both sides and used as the major input for the measures of effectiveness the model produces.

The model is divided into 5 major pieces. The first piece is where all of the inputs are gathered and values common to all of the strikes are calculated. The next four pieces contain calculations for eight distinct strikes:

- War Initiating 1st Strike for Side/Coalition A and Side/Coalition B
- Initial Retaliation Strike for Side/Coalition A and Side/Coalition B
- Reserve Strike subsequent to a war initiating first strike for both sides/coalitions
- Reserve Strike subsequent to a retaliatory strike for both sides/coalitions

Each strike is divided into 3 sections

- Penetration
- Targeting
- Survival

The planning section of the model lays out the forces available, and their basic characteristics, such as yield, reliability (probability of launch and detonation), and guidance on employment – alert rates, how many weapons should be allocated to which strike, and what targets, etc.

Guaranteed Retaliatory Capability
Guaranteed Retaliatory Capability is formalized as:

$$R_g = \underbrace{w_m \times p_{sm} \times p_l \times p_{pm} \times p_d}_{\text{Main Strike}} + \underbrace{w_r \times p_{sr} \times p_l \times p_{pr} \times p_d}_{\text{Reserve Strike}}$$

where:

R_g Guaranteed retaliatory capability
w_m Weapons available for retaliatory strike
p_{sf} Probability of Surviving Enemy 1st strike
p_l Probability of Launch
p_{pr} Probability of Penetration for Retaliatory strike
p_d Probability of Detonation
w_r Weapons available reserve strike
p_{sr} Probability of Surviving Enemy Reserve strike
p_{pr} Probability of Penetration for Reserve strike

Averted Losses
Averted Losses is formalized as:

$$l_a = \underbrace{(w_f \times p_l \times p_{pf} \times p_d)}_{\text{[Enemy 1st Strike]}} - \underbrace{(w_r \times p_{sr} \times p_l \times p_{pr} \times p_d)}_{\text{[Enemy Retaliatory Strike]}}$$

where:

l_a Averted Losses

w_m Weapons available for 1st strike

p_{lr} Probability of Launch

p_{pr} Probability of Penetration of 1st strike

p_{dr} Probability of Detonation

w_r Weapons available for Retaliatory strike

p_{sr} Probability of Survival of Retaliatory strike

p_{pr} Probability of Penetration for Reserve strike

Balance
Balance is formalized as:

$$B_{ib} = \frac{(w_f \times p_l \times p_{pf} \times p_d) + (w_{rr} \times p_{sr} \times p_l \times p_{pr} \times p_d)}{(w_f \times p_l \times p_{pf} \times p_d) + (w_{rr} \times p_{sr} \times p_l \times p_{pr} \times p_d)}$$

$$B_{prb} = \frac{(w_{rr} \times p_{sr} \times p_l \times p_{pr} \times p_d)}{(w_r \times p_l \times p_{pf} \times p_d) + (w_{rr} \times p_{sr} \times p_l \times p_{pr} \times p_d)}$$

$$B_{pbr} = \frac{(w_{rr} \times p_{sr} \times p_l \times p_{pr} \times p_d)}{(w_r \times p_l \times p_{pf} \times p_d) + (w_{rr} \times p_{sr} \times p_l \times p_{pr} \times p_d)}$$

where:

B_{ib} Initial balance (from Blue's perspective)
B_{ib} Post Blue 1st Strike balance (from Blue's perspective)
B_{ib} Post Red 1st Strike balance (from Blue's perspective)
w_f Weapons available for first strike
w_r Weapons available for retaliation strike
p_{sf} Probability of Surviving Enemy 1st strike
p_l Probability of Launch
p_{pr} Probability of Penetration for Retaliatory strike
p_d Probability of Detonation
w_{rr} Weapons available reserve strike
p_{sr} Probability of Surviving Enemy Reserve strike
p_{pr} Probability of Penetration for Reserve strike

Weapon Availability
Recall that

$$w_e = w_a \times p_s \times p_l \times p_p \times p_d$$

We formalize weapon availability as:

$$w_a = w \times a_s \times r_a$$

where w is weapons, a_s is strike allocation (the percent of forces intended for a particular strike), and r_a is alert rate (the percent of forces on-line, not down for maintenance).

Probability of Survival
We formalize the probability of survival as:

$$p_s = \frac{(w \times r_a) + (w_a - w_{at}) + (w_{at} \times p_{sv})}{w}$$

W_a is weapons available. R_a is alert rate. For mobile weapons, this is the percent at sea, in the air, or out of garrison at 0 hour. For silo-based weapons, this is the percent ready for launch under attack. W_{at} is weapons attacked (based on the number of weapons available, number of weapons required to achieve desired probability of damage, projected reliability, and probability of penetration). W_{na} is weapons not attacked. P_{sv} is based on target hardness, and number, yield, accuracy, reliability, and penetration of weapons allocated.

Therefore,

$$p_{sv} = p_{svr}^{\,w_a}$$

$$w_r = \frac{1}{\log(p_{svr}) \div \log(damage_{rqmt})}$$

$$P_{svr} = 0.5^{\left(\frac{yield^{2/3}}{accuracy^{2}} \div \left(\frac{hardness}{16}\right)^{2/3}\right)} \times p_l \times p_p \times p_d$$

$yield$	Megatonnes
$accuracy$	CEP in nautical miles
$hardness$	Pounds per square inch
$damage_{rqmt}$	Probability of Destruction Required
p_{svr}	Raw probability of survival
p_l	Probability of launch (Reliability)
p_p	Probability of penetration
p_d	Probability of detonation (Reliability)
w_r	Weapons required
w_a	Weapons allocated (Equals weapons required to point of exhaustion, then zero)

Probability of Penetration

Probability of Penetration is formalized as:

$$p_p = \frac{(w_a - w_e) + (w_e \times (1\text{-}P_k)^{f_d})}{w_e}$$

$$w_e = \frac{i_a}{f_d} \times \frac{w_a}{w_a + d_a}$$

W_a is offensive weapons in strike, w_e is weapons engaged (based on the number of interceptors available, p_k is the probability of kill, f_d if firing doctrine (based on the number of interceptors and expected raid size), i_a is interceptors available, and d_a is decoys in strike (based on system characteristic of credible decoys per warhead).

Assumptions and Limitations
We assume that planning is done with perfect knowledge of offensive and defensive capabilities. In addition, we make several simplifying assumptions regarding targeting:

- Targets are limited to two categories – strategic offensive forces (silos, sub bases, main airbases), and other (bunkers, dispersal fields, military bases, c^2 nodes, war supporting industries, urban areas).
- Alert, non-silo based forces are not targetable.
- The geographic distribution of targets is not considered.
- Each target is affected independently.
- Offensive force targeting is not optimized, but rather starts with the softest targets, and then weapons are allocated in order of appearance in the database.

Further, regarding offense performance, the damage model is based on overpressure only. Finally, regarding defense performance, we assume that strikes and credible decoys are uniformly distributed, and that the firing doctrine is derived with perfect knowledge of raid size.

Definition of Terms
Bases – Bases translates the number of weapons of a given type into the number of targets needed to attack that weapon type. For example, large numbers of aircraft are concentrated on a small number of airbases. The variable bases is used to determine how many warheads must be allocated to attack bombers and submarines that are not on patrol, airborne, and will be unable to put to sea or take off before the incoming warheads arrive. The variable assumes bombers and submarines not on patrol, airborne, and will be unable to put to sea or take off before incoming warheads arrive are concentrated on bases, so that a single warhead might kill large numbers of them.

Silos-Platforms/Base – the multiplier applied to the number of silos or platforms to calculate the number of bases for each weapon type.

Platform Name – Indicates for the user the name of the platform on which the weapon can be found. For example, the Platform Name for a Trident D5 missile is Ohio, for the Ohio class SSBN that carries them.

Silos/Platforms – The number of platforms

Missiles-Systems/Platform – The number of missiles or weapons the platform carries.

System-Weapon Name – Indicates for the user the name of the weapon system. For example, Peacekeeper, or AS-15.

Missiles/Weapons – The number of missiles, cruise-missiles or bombs

Warheads/Missile – The number of warheads each missile or weapon carries.

Warheads – The number of warheads present for each weapon system type.

Warheads/Missile (Treaty) – For START, counting rules are used where the actual number of warheads per weapon can vary from the number as counted for treaty purposes.

Warheads (Treaty) – The number of warheads for each weapon type, per the START treaty counting rules. Used to keep overall-force levels in line with the treaty in consideration.

Yield – Weapon yield in megatons.

Accuracy – Weapon accuracy in nautical miles.

Credible Decoys per Warhead – a simple means for representing countermeasures that force expenditure of additional interceptors per actual threat object (decoys and replicas, shrouded RVs).

PK Modifier – not currently used. Meant to represent countermeasures that reduce the effectiveness of individual interceptors (chaff, jamming, signature modification, maneuvers).

Hardness – in pounds per square inch. Used in the damage calculations to determine weapon system survivability.

Launch Reliability – Percentage. The probability that the weapon system successfully makes it off its base or out of its silo, and through its preliminary flight phases.

Detonation Reliability – Percentage. The probability that once launched, and through any present defenses, the weapon detonates over or on its target.

Damage requirement – Percentage. The required probability of destruction. For each weapon type, used to calculate how many warheads should be employed against each target type. The higher the desired damage, the more weapons must be thrown at each target type.

Main Strike Allocation – Percentage. The model assumes that each side organizes their weapons into a main force, and a reserve force, and that the apportionment does not change based whether a side goes first or second. This parameter allows the user to allocate a particular weapon type the main strike force.

Operational Reserve Allocation – Percentage. The model assumes that each side organizes their weapons into a main force, and a reserve force, and that the apportionment does not change based whether a side goes first or second. This parameter is calculated assuming that what ever inventory is not used in the main strike is allocated to the operational reserve.

1st Strike Alert Rate – Percentage. Defines the percentage of the total force available for a 1st strike. The model presumes that if a side determined that it was going to initiate nuclear war, it might bring its forces to a hyper state of readiness even higher than the “fully” generated rate it might operate at during times of heightened alert.

Retaliation Alert Rate – Percentage. Defines the percentage of the total force available for retaliation. In peace time, this alert rate might be quite low. Weapons in silos that are on alert are considered to be capable of launching under attack. Weapons on SSBNs are considered to be at sea. Weapons on bombers are considered to be aboard aircraft that are either on airborne alert, or in such an alert state that they can launch under attack.

Launch Posture – Rideout or LUA. Silo-based weapons with rideout will be subjected to attack. Not a factor yet for other weapon types.

1st Strike Strat – SOF or Other. Allows the user to select whether the weapon type will be used against the other sides’ offensive forces (silos, bomber bases, and sub pens).

Defend SOF – yes or no. Allows the user to select whether a side’s defenses will be used against the other sides weapons that are inbound to SOF targets.

Retaliation Strat – SOF or Other. Allows the user to select whether a weapon type will be employed against the other sides’ residual offensive forces (silos, bomber bases, and sub pens)

Raw Ps of 4000 psi tgt – The raw probability of survival of a target of the indicated hardness when attacked by a single warhead of the given type.

$$P_s = 0.5^{\frac{yield^{2/3}}{accuracy^2} \div \left(\frac{hardness}{16}\right)^{2/3}}$$

where

yield is in megatonnes
accuracy is in nautical miles
hardness is in pounds per square inch

Raw Ps of 2000 psi tgt – See above.

Raw Ps of 300 psi tgt – See above.

Raw Ps of 300 psi tgt – See above.

Raw Ps of 3 psi tgt – See above.

Ps of 4000 psi tgt – The probability of survival of a target of the indicated hardness, when attacked by a single warhead of the given type, with the probability of launch, detonation, and penetration rate included. Used in conjunction with the damage requirement specified to determine how many warheads should be allocated to each target type. Penetration is calculated as described below. Note that this allows planning to occur with perfect knowledge of penetration.

$$P_s = 0.5^{\left(\frac{yield^{2/3}}{accuracy^2} \div \left(\frac{hardness}{16}\right)^{2/3}\right)} \times p_l \times p_p \times p_d$$

where

yield is in megatonnes
accuracy is in nautical miles
hardness is in pounds per square inch
p_l is the probability of launch
p_p is the probability of defense penetration
p_d is the probability of detonation

Ps of 2000 psi tgt – See above.

Ps of 300 psi tgt – See above.

Ps of 3 psi tgt – See above.

Number of 4000 psi Targets – calculated by hardness and the number of bases. Represents a super-hardened silo

Number of 2000 psi Targets – calculated by hardness and the number of bases. Represents a silo hardened a level similar to that attributed to modern US silos.

Number of 300 psi Targets – calculated by hardness and the number of bases. Represents a semi-hard target, such as a SSBN at port.

Number of 30 psi Targets – calculated by hardness and the number of bases. Represents a semi-soft target, such as a hardened TEL.

Number of 3 psi Targets – calculated by hardness and the number of bases. Represents a soft target, such as a rail car, or a bomber,

Whds required vs 4000 psi tgt – The number of warheads required to achieve the damage requirement defined for a weapon type. If P_s is 100%, set to 0.

$$w_r = \frac{1}{\log(p_s) \div \log(damage_{rgmt})}$$

where

w_r = warheads required
p_s = probability of survival
$damage_{rqmnt}$ = the probability of destruction

Whds required vs 2000 psi tgt – See above.

Whds required vs 300 psi tgt – See above.

Whds required vs 30 psi tgt – See above.

Whds required vs 3 psi tgt – See above.

Interceptor Type – Boost Phase, Mid-Course or Terminal. Three types of defenses are allowed. They represent individual layers. The model assumes only one type of defense is allowed per layer. Boost phase defenses engage ballistic missiles before any warheads or pen-aids are released. Mid-course defenses engage individual warheads and pen-aids. Terminal defenses represent a last line of defense.

Interceptors – The number of ballistic missile interceptors. Could also be thought of as roughly equivalent to lases, or engagements.

Coverage – A term meant to capture range constraints for a given ABM interceptor type that might prevent it from engaging all of the threats, regardless of where the threat is launched from, or where it is going to, and where these points are in relationship to the defense site location.

P_k – The probability an ABM intercept will result in a warhead killed.

1^ST^ Strike FIDOC – Defines the number of ABM interceptors expended per threat object part of a 1st strike. If there is sufficient inventory, the defense will through more than one interceptor at each threat object for as many objects as it can. If there isn't sufficient inventory, the defense will use a FIDOC of one interceptor against as many objects as possible.

Retaliation FIDOC - Defines the number of ABM interceptors expended per threat object part of a retaliatory strike. Distinguished from 1st Strike doctrine to maximize the effect of engaging a ragged retaliation.

Operational Res FIDOC, Retaliation – Defines the number of ABM interceptors expended per threat object part of the second strike launched by the 1st striker.

Operational Res FIDOC, 1st Strike – Defines the number of ABM interceptors expended per threat object part of the second strike launched by the retaliator.

Max Expended/Raid – Allows ABM interceptors to be withheld for future raids.

Air Defense Type – Forward, Peripheral, or Terminal. Three layers of air defense are modeled. Forward air defenses are meant to represent intercept aircraft that are capable of engaging enemy bombers before they have a chance to launch their cruise missiles. Peripheral defenses are meant to represent an additional layer of ground based and air based defenses that would engage penetrating bombers and cruise missiles. Terminal defenses are meant to represent a final layer of defenses.

Initial AD Effectiveness – The percentage of the air raid negated by the air defense during the main exchange.

Final AD Effectiveness – The percentage of the air raid negated by the air defense during the operational reserve exchange.

Penetration Sections – Includes 1st Strike Penetration, Retaliation Strike Penetration, Operational Reserve Strike (1st Strike) Penetration, Operational Reserve Strike (Retaliation) Penetration.

1st Strike/Retaliation/Op Reserve Boosters – The number of boosters of a particular weapon type allocated for the particular strike.

1st Strike/Retaliation/Op Reserve Warheads – The number of warheads of a particular weapon type allocated for the particular strike.

Effective Boosters – The number of boosters of a particular weapon type taking probability of launch into account.

Effective Warheads – The number of warheads of a particular weapon type, taking probability of launch into account.

Boosters Engaged – The number of boosters engaged by the boost phase defenses. Calculated taking boost phase interceptor inventory, coverage, and the number of boosters into account.

Boosters Leak – The number of boosters not destroyed by the boost phase defenses.

Effective Warheads – The number of warheads deployed off of the surviving boosters.

Effective Decoys – The number of credible decoys accompanying the warheads, based on the credible decoys per warhead for the particular weapon type.

Total Objects – the number of warheads plus the number of decoys the next layer of the defense must engage.

Objs for Eng – If the side is to defend SOF targets, the same as Total Objects. If only non-SOF targets are to be defended, the number of warheads and accompanying decoys bound for non SOF targets.

Total Engaged – The number of warheads and decoys engaged, based on interceptor inventory, coverage, and the number of objects into account.

Decoys Engaged – The number of decoys engaged, based on the proportion of decoys in the strike.

Warheads Engaged – The number of warheads engaged, based on the proportion of warheads in the strike.

Eng Dec Leakers - The number of engaged decoys that leak through the defense.

Dec Leakers – The total number of decoys that penetrate the defense layer.

Eng Wh Leakers - The number of engaged warheads that leak through the defense.

Wh Leakers – The total number of warheads that penetrate the defense layer.

Total Objects – the number of warheads plus the number of decoys the next layer of the defense must engage.

Objs for Eng – If the side is to defend SOF targets, the same as Total Objects. If only non-SOF targets are to be defended, the number of warheads and accompanying decoys bound for non SOF targets.

Total Engaged – The number of warheads and decoys engaged, based on interceptor inventory, coverage, and the number of objects into account.

Decoys Engaged – The number of decoys engaged, based on the proportion of decoys in the strike.

Warheads Engaged – The number of warheads engaged, based on the proportion of warheads in the strike.

Eng Dec Leakers - The number of engaged decoys that leak through the defense.

Dec Leakers – The total number of decoys that penetrate the defense layer.

Eng Wh Leakers - The number of engaged warheads that leak through the defense.

Wh Leakers – The total number of warheads that penetrate the defense layer.

1st – Retaliation – Operational Reserve Strike Penetration – The percentage of warheads that leak (in relation to the number of effective warheads included in the strike).

Targeting Sections (1st Stike Targeting, Retaliation Targeting) - The only targeting considered in the model is against Strategic Offensive Forces. In addition, only those targets that directly relate to the basing of operational force are considered. Dispersal fields, tanker airbases, alternate fields, nuclear storage, command and control facilities are not considered. Finally, targeting is only taken into consideration for the preliminary exchange. The model assumes that the reserve exchange does not involve SOF targets.

3 psi Targets Targeted – The number of 3 psi targets a particular weapon type will attack, based on the number of available weapons, and the number of warheads required per target to achieve the desired level of destruction, and the number of targets that have not been targeted by other weapons.

Cumulative 3 psi Targets Targeted – stores the number of 3 psi targets that have already had sufficient weapons allocated. Used to determine the number of targets that have not been targeted by other weapons.

Warheads Expended vs 3 psi Targets – based on the number of targets targeted, and the weapons allocated per target.

3 psi Targeted Targets Surv – based on the number of warheads, and the probability of survival for a given weapon type and target hardness (calculated earlier), the number of aim-points that do not receive the desired level of damage. Systems at these aim-points are considered to survive the strike as calculated below.

30 psi Targets Targeted – as per the 3 psi entry, except that the number of weapons of a given type available to be expended vs 30 psi targets is reduced by the number of weapons of that type expended against 3 psi targets.

Cumulative 30 psi Targets Targeted – See above.

Warheads Expended vs 30 psi Targets - See above.

30 psi Targeted Targets Surv – See above.

300 psi Targets Targeted – as per the 30 psi entry, except that the number of weapons of a given type available to be expended vs 300 spi targets is reduced by the number of weapons of that type already expended against other targets.

Cumulative 300 psi Targets Targeted – See above.

Warheads Expended vs 300 psi Targets - See above.

300 psi Targeted Targets Surv – See above.

2000 psi Targets Targeted – See above.

Cumulative 2000 psi Targets Targeted – See above.

Warheads Expended vs 2000 psi Targets - See above.

2000 psi Targeted Targets Surv – See above.

4000 psi Targets Targeted – See above.

Cumulative 4000 psi Targets Targeted – See above.

Warheads Expended vs 4000 psi Targets - See above.

4000 psi Targeted Targets Surv – See above.

Warheads Available for Other Targets – All weapons allocated to a strike that are not used against the SOF targets indicated are available for attacking other targets. The model assumes that the vast majority of these other targets are related to the national economy and population centers.

Survival Sections (1st Strike Survival, Retaliation Survival) - Survival of forces is calculated for both when a side faces a first strike, or a retaliatory strike. The model assumes that once the initial exchanges have occurred, no further attacks on SOF take place.

On Base, At Port, In Silo at 0 Hour – The number of platforms that can be attacked with weapons.

On patrol, in-Flight, at H hour – The number of platforms that can't be attacked with weapons, because they left the location of the targeted aim-points.

Non-targetable Warheads (at 4000 psi Targets) – The number of warheads that can't be attacked with weapons, because they are on platforms that have left the vicinity of the targeted aim-points.

Targetable Warheads (4000 psi Targets) Not Targeted – Those warheads that could potentially be targeted but aren't mostly due to lack of appropriate inventory.

Surviving Targetable (4000 psi)Warheads Targeted – Those warheads that were targeted and attacked that did not sustain the required level of damage.

Non-targetable Warheads (at 2000 psi Targets) – The number of warheads that can't be attacked with weapons, because they are on platforms that have left the vicinity of the targeted aim-points.

Targetable Warheads (2000 psi Targets) Not Targeted – Those warheads that could potentially be targeted but aren't mostly due to lack of appropriate inventory.

Surviving Targetable (2000 psi)Warheads Targeted – Those warheads that were targeted and attacked that did not sustain the required level of damage.

Non-targetable Warheads (at 300 psi Targets) – The number of warheads that can't be attacked with weapons, because they are on platforms that have left the vicinity of the targeted aim-points.

Targetable Warheads (300 psi Targets) Not Targeted – Those warheads that could potentially be targeted but aren't mostly due to lack of appropriate inventory.

Surviving Targetable (300 psi)Warheads Targeted – Those warheads that were targeted and attacked that did not sustain the required level of damage.

Non-targetable Warheads (at 30 psi Targets) – The number of warheads that can't be attacked with weapons, because they are on platforms that have left the vicinity of the targeted aim-points.

Targetable Warheads (30 psi Targets) Not Targeted – Those warheads that could potentially be targeted but aren't mostly due to lack of appropriate inventory.

Surviving Targetable (30 psi)Warheads Targeted – Those warheads that were targeted and attacked that did not sustain the required level of damage.

Non-targetable Warheads (at 3 psi Targets) – The number of warheads that can't be attacked with weapons, because they are on platforms that have left the vicinity of the targeted aim-points.

Targetable Warheads (3 psi Targets) Not Targeted – Those warheads that could potentially be targeted but aren't mostly due to lack of appropriate inventory.

Surviving Targetable (3 psi)Warheads Targeted – Those warheads that were targeted and attacked that did not sustain the required level of damage.

Survivability – the percentage of weapons that survive a particular strike.

APPENDIX A:
Differences between Tasks 3.2 and 3.3

As is to be expected, the computer model differs in some respects from the theoretical model designed in Task 2. In order to minimize misunderstanding, this section identifies and explains those points of difference.

Risk of technology breakout. In the theoretical discussion, we noted that an actor may fear that another player would suddenly achieve a technological breakthrough, and therefore a capability advantage. Operationalizing this concept in a literal manner proved difficult, in that computational practicalities force limits on the players' ability to foresee the future. Instead, we use two surrogate methods to operationalize the concept of technology breakout. First, the systems database contains a detailed listing of potential systems. Second, those systems contain an availability year, or a time in which technology will allow the system to be produced. The user is free to manipulate both the details of the systems and the year in which they would "come on-line." Thus while the model does not allow a user to examine the perceived risk of technology breakout, the user can make a precise evaluation of the impact of hypothetical technology breakout.

Deterrence/stability equations. The equations in the text are a summary overview of the nuclear exchange model embedded in the simulation. The Task 3 Report illuminates the full model.

Pk measures. The text notes that Pk measures are consistent throughout the model run, except for the addition of an alliance partner. The mathematical model explicitly details the inputs that lead to Pk, subsuming this particular point.

End-state. The text suggests that the model will run until a pre-defined end-state is reached. To allow the user more flexibility, the model will run one round at a time, allowing Blue to make changes along the way. The user can continue running rounds until the year 2020, or the user can stop at any time.

Stored scenarios. The text lists several scenarios that the user can run. To maximize flexibility, the user can effectively choose from a long list of scenarios, by varying multiple factors.

APPENDIX B:
Literature Review and Bibliography

This appendix discusses the work of Task 3.1, as well as the data sources employed in Task 3.3.

Introduction

This essay reviews the literature that addresses strategic offensive forces, strategic defensive forces and threat reduction measures, especially works that consider the relationship among them. The study of strategic offensive forces against adversary strategic offensive forces has been a constant for the past four decades. Research into the offense-defense strategic relationship has intensified at three distinct eras in response to the consideration of missile defenses: the 1960s period of initial Anti-Ballistic Missile (ABM) possibilities, the 1980s period of Strategic Defense Initiative (SDI) research, and the 1990s to today, with the more realistic prospects for a limited US National Missile Defense (NMD). Consideration of arms control/threat reduction measures has also been examined over the past four decades, albeit in a manner largely distinct from trade-offs between strategic offensive and defensive forces.

This literature review addresses three distinct issues. First, what are types and best sources of work in this area. Second, what are primary substantive findings. Third, what are the key methodological issues in the study of these strategic relationships including specification of the dependent and independent variables and complexity of the models. The report concludes with an overarching assessment of the literature. The bibliography, included as an appendix, lists 155 documents that are relevant to the study task.

Literature Types

Research on this subject breaks into three broad categories: deductive arguments, inductive assessments, and deductive models. Each approach has particular strengths and weaknesses for evaluating strategic issues. This section begins by briefly reviewing the deductive arguments and inductive assessments before turning to deductive models at length.

Deductive Arguments

Arguments based on deduction formed the foundation of early assessments of strategic offenses, strategic defenses, and arms control. For example, Bernard Brodie deduced in *The Absolute Weapon* that the threat of nuclear weapons use inevitably would make nuclear war unthinkable. Herman Kahn deductively examined the logic of the escalation ladder and war termination in his seminal work, *On Thermonuclear War*. Thomas Schelling considered the inherent fragility of deterrence and the importance of resolve in his 1960 work, *The Strategy of Conflict*. In addition, Schelling co-authored with Morton Halperin a deductive exploration of opportunities for arms control in *Strategy and Arms Control*.

The popularity and importance of deductive argument in these analyses reflected one of the fundamental problems in assessing strategic offenses, strategic defenses, and arms control: *a lack of data*. Testimony from Manhattan project scientists and the data from the US use of atomic weapons against Japan provided evidence that nuclear weapons were fundamentally new in their effects and implications. As a consequence, strategists such as Brodie were forced to rely on deduction to forecast how these new weapons would change the ways that wars would be fought.

The fact that nuclear weapons have not been detonated in combat since 1945, thus, has required that a significant segment of the work conducted during the post-World War II period employ deductive methodologies. One of the most important studies in this tradition is Robert Jervis' "Cooperation Under the Security Dilemma," in which the author deduces what he perceives to be the fundamental dilemma at the heart of the international system: "the means by which a state tries to increase its security decrease the security of others."[20] Jervis concludes that two variables help to explain the relative danger of the security dilemma: 1) whether defensive weapons can be distinguished from offensive ones, and 2) whether the offense has the advantage.[21] Figure 1 portrays the implications of Jervis' deductive analysis.

	Offense has the Advantage	**Defense has the Advantage**
Offensive Posture Not Distinguishable from Defensive One	***Doubly Dangerous***	***Security dilemma, but security requirements may be compatible***
Offensive Posture Distinguishable from Defensive One	• ***No security dilemma, but aggression possible*** • ***Status-quo states can follow different policy than aggressors*** • ***Warning given***	***Doubly Stable***

Building off of Jervis' examination of the structure of competition in strategic offenses and defenses, others have used deductive reasoning to explore opportunities for strategic cooperation – either through behavioral rules of the game or arms control. For example, Robert Axelrod uses the logic of economic models – the Prisoner's Dilemma, in

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[20] Robert Jervis, "Cooperation Under the Security Dilemma," reprinted in Robert Art & Kenneth Waltz, eds., *The Use of* Force, 3rd Edition, (The University Press of America, 1988) p. 69.
[21] Jervis, p. 70.

particular – to explore means of structuring incentives for cooperation.[22] Among others, George Downs and David Rocke, have similarly used deductive reasoning and game theory to explore the role of tacit bargaining to control or avoid arms racing behavior.[23]

Deductive arguments additionally played a central role in discussions of deterrence and nuclear strategy during the 1980s. In particular, deductive reasoning was at the heart of debates of whether the condition of Mutual Assured Destruction (MAD) existed or was desirable. For example, theorist Colin Gray took issue with MAD-proponents when he deduced that the US nuclear deterrent strategy could not be effective unless it was supported by forces of adequate number of capability to be used in a practical way. To that end, Gray argued that the US should strive for a policy of *strategic superiority* rather than *equality* with the Soviet Union.[24]

Many deductive arguments increasingly employ sophisticated game theory, especially to identify and understand actor preferences. Works by Barry O'Neill, Marc Kilgour, Frank Zagare, Paul Huth, and Charles Glaser exemplify this approach. In 1994, O'Neill published a comprehensive analysis of game theory efforts on peace and war including approaches to arms racing, deterrence signaling, crisis stability, war escalation, and arms control verification.[25] The majority of game theory studies assess the probability of conflict escalation or deterrence based on the balance of military capability, objectives, and credibility. In addition, recent game theory approaches include methodologies for assessing the credibility of arms control programs and confidence building measures.

Inductive Arguments

Although nuclear weapons have not been used in combat since 1945, by the 1980s there nevertheless was a considerable history of explicit and implicit *threats* of their use. Most importantly, the history of Cold War crises provided empirical data with which social scientists could analyze the dynamics of deterrence and arms races. This research opportunity provided a means to address complaints from the likes of Alexander George and Richard Smoke, who argued that deductive reasoning could do little to help with policy prescription.[26]

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[22] In particular, Axelrod found conclusively that the principle of reciprocity has enormous impact on the securing of cooperative behavior. See Robert Axelrod, *The Evolution of Cooperation*, (NY: Basic Books, 1984).

[23] George W. Downs and David M. Rocke, *Tacit Bargaining, Arms Races, and Arms Control*, (Ann Arbor, University of Michigan Press, 1991).

[24] Colin Gray, "Nuclear Strategy: A Case for a Theory of Victory," in Steven E. Miller, ed., *Strategy and Nuclear Deterrence*, (Princeton: Princeton University Press, 1984), pp. 54-56. For an argument that nuclear weapons neither detract from, nor contribute to, stability, see John Mueller, "The Essential Irrelevance of Nuclear Weapons: Stability in the Postwar World," *International Security*, 13:2, (Fall 1988).

[25] O'Neill, Barry. "Game Theory Models of Peace and War" in Aumann, Robert J. and Sergio Hart, eds. *Handbook of Game Theory with Economic Applications*. Amsterdam. Elsevier Science B.V., 1994.

[26] George and Smoke argue that "the contemporary abstract, deductivistic theory of deterrence is inadequate for policy application." See Alexander George and Richard Smoke, *Deterrence in American Foreign* Policy, (NY: Columbia University Press, 1974), p. 503.

Depending upon their epistemological preferences, analysts working inductively relied on quantitative or, more often, qualitative methodologies. Among the most prominent analysts employing quantitative approaches to the study of these subjects were Bruce Russet and Paul Huth. In several statistical analyses of historical cases, Huth and Russet were able to examine the conditions explaining the failures and successes of deterrence in 54 historical cases.[27]

Yet the majority of inductive researchers working on strategic offenses, defenses, and arms control employ case study and related methodologies. These studies range from rigorous applications of focused comparison of case studies as used by George and Smoke, to single in-depth case studies such as used by Janice Gross Stein, to more anecdotal research approaches.[28]

In order to explore the dynamics of crisis stability, a number of inductive analysts additionally have explored cases that, while non-nuclear in character, might have implications for nuclear era crises. During the 1980s and early 1990s, perhaps the most popular historical case in this regard was the origins of World War I. Analysts such as Jack Levy, Sean Lynn-Jones, Scott Sagan, Marc Trachtenberg, and Stephen Van Evera explored the offense/defense balance, misperceptions, and a range of other factors that they argued contributed to the breakdown of deterrence and the outbreak of an undesired World War.[29]

Deductive Models

Findings from the research employing deductive arguments and inductive assessments influence the assumptions, variables, and parameters used in deductive modeling efforts. The remainder of the literature review focuses on these deductive models in consonance with the project's primary aim of developing a model that captures the relationship of strategic offensive forces, strategic defensive forces, and threat reduction.

Modeling efforts on the topic have been completed primarily by researchers at universities, government institutions, especially DOE's nuclear weapons laboratories, and federally-funded research and development centers (FFRDCs). The attached

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[27] See, for example, Paul Huth and Bruce Russet, "What Makes Deterrence Work? Cases from 1900 to 1980," *World Politics*, July 1984, pp. 496-526; and "Testing Deterrence Theory: Rigor Makes a Difference," *World Politics* (July 1990), pp. 466-501.

[28] See Janice Gross Stein, "Calculation, Miscalculation, and Conventional Deterrence: The View from Cairo," in Robert Jervis, Richard Ned Lebow, and Janice Gross Stein, *Psychology and Deterrence*, Baltimore, The Johns Hopkins University Press, 1985); and Richard Ned Lebow, "Between Peace and War: The Nature of International Crisis," (Baltimore: The Johns Hopkins University Press, 1981).

[29] See Jack S Levy, "Preferences, Constraints, and Choices in July 1914," *International Security,* 15:3 (Winter 1990/91), 151-186; Sean M. Lynn-Jones, "Detente and Deterrence: Anglo-German Relations, 1911-1914," *International Security,* 11:2 (Fall 1986), 121-150; Scott D. Sagan, "1914 Revisited: Allies, Offense, and Instability," *International Security*, 11:2 (Fall 1986), 151-175; Marc Trachtenberg, "The Meaning of Mobilization in 1914," *International Security*, 15:3 (Winter 1990/91), 120-150; and Stephen Van Evera, "The Cult of the Offensive and the Origins of the First World War," *International Security,* 9:1 (Summer 1984), 58-107.

bibliography reflects this breakdown with a concentration of publications from academic journals and FFRDC presses. In compiling this literature, the study team noted particularly strong contributions from analysts at Stanford University's Center for International Security and Cooperation (CISAC), the RAND Corporation, the Institute for Defense Analysis (IDA), the Los Alamos National Laboratory (LANL) and the Lawrence Livermore National Laboratory (LLNL).

Analysts who have particularly explicated the linkages between strategic offensive forces and strategic defensive forces, and to a lesser extent threat reduction measures, deserve mention. Dean Wilkening (CISAC) has developed a probabilistic model analyzing the effectiveness of ballistic missile defenses.[30] His current work focuses on optimizing US BMD deployment strategies to counter the threat from "states of concern" while minimizing the impacts on strategic stability with Russia, China, Britain and France. Greg Canavan (LANL) is one of few researchers who has continuously investigated strategic stability issues since the SDI era. He has authored numerous technical reports that evaluate various force configurations against indices of strategic stability.[31] His models primarily evaluate the impact of various offense-offense and offense-defense exchanges with recent work including the effect of threat reduction measures such as dealerting. Recent and ongoing work by other LANL researchers includes development of a high-resolution multi-polar strategic force planning and stability model.[32] Jerome Bracken and other IDA researchers recently developed an offense – defense exchange model to analyze how the deployment of US BMD would affect deterrence and stability with Russia.[33] The model was also used to analyze the affects of proposed stabilization measures, including threat reduction components such as alert status and terms of use. Although dating from the 1980s, Glenn Kent and Randall de Valk (RAND) and Paul Chrzanowski (LLNL) laid the groundwork for analyzing the transition from an assured retaliation, punishment-based deterrence to defense-based deterrence.[34] They independently developed offense – defense exchange models that evaluated scenarios and their outcomes based on first-strike stability measures. In 1988, Ivan Oelrich and Jerome Bracken (IDA) compiled a useful report evaluating and contrasting strategic stability transition models.[35]

[30] Wilkening, Dean. "A Simple Model for Calculating Ballistic Missile Defense Effectiveness," Stanford, CA: Center for International Security and Cooperation, 1998.
[31] For example, see "Considerations in Missile Reductions and Dealerting," Los Alamos, NM: LA-UR-98-1426, February, 1997 and "Freedom to Mix Vulnerable Offensive and Defense Forces," Los Alamos, NM: LA-UR-98-3938, September, 1998.
[32] "MESA/SM Multiple Engagements of Strategic Arsenals w/Stability Metrics," briefing prepared for DTRA: Los Alamos National Laboratory.
[33] Bracken, Jerome, James Scouras and Victor Utgoff. "Offense-Defense Strategic Nuclear Deterrent Stability Summary and Conclusions," Alexandria, VA: Institute for Defense Analysis, 1998.
[34] Kent, Glenn and Randall de Valk. "Strategic Defenses and the Transition to Assured Survival," Santa Monica, CA: RAND, R-3369-AF, October 1986 and Chrzanowski, Paul. "The Transition to a Deterrence Posture More Reliant on Strategic Defenses," Lawrence Livermore National Laboratory, 1988.
[35] Oelrich, Ivan and Jerome Bracken. "A Comparison and Analysis of Strategic Defense Transition Models," IDA Paper P-2145. Alexandria, VA: Institute for Defense Analysis, 1988.

Substantive Findings

The study team has identified four main themes that emerge from the literature. The aforementioned empirical research and deductive arguments largely generated these ideas. Modelers have subsequently taken them as either assumptions or matters to be evaluated through formal examination. First, the maintenance of strategic stability against nuclear attack requires an *effective* and *stable* deterrent, even though the definition of a stable deterrent varies by state. Second, the optimal strategic stability environment results from states possessing mutual and minimal *offensive* deterrent forces with highly survivable delivery systems carrying low-levels of warheads. Third, advances in technology can and do dramatically affect strategic stability. Lastly, actors' perceptions of intentions and vital interests critically impact nuclear deterrence. These findings should be considered strictly in terms of nuclear environments. Their applicability to exclusively conventional situations is uncertain at best, and to some extent clearly not germane.

Above all, analysts stress that the maintenance of strategic stability against nuclear attack requires an effective and stable deterrent. The maturation of strategic offensive forces, especially ballistic missiles, far before strategic defensive forces led to a focus on how to achieve deterrence and strategic stability through mutually assured destruction. With ballistic missile defenses easy to defeat, and then largely outlawed with the ABM treaty, strategic stability models explored offensive exchanges only, with the critical determination being the existence of a second-strike capability of a sufficient force to deter the adversary. Diminishing returns were noted for upgrading highly diverse and capable nuclear forces. Thus, analysts regarded strategic offensive arms racing as destabilizing and counterproductive after reaching assured destruction threshold levels. These conclusions helped propel a series of arms control arrangements between the US and USSR.

The initiation of SDI research prompted analysts again to consider the impact of defenses on strategic stability given the theoretical possibility of achieving deterrence through denial. The literature considers only two forms of deterrence: assured response capability achieved through survivable offensive forces, or assured survival capability achieved through implementation of a cost and performance effective strategic defensive force. The latter has significant moral and ethical appeal, but most of the research conducted in the 1980s concluded that deployment of defensive forces creates potentially unstable scenarios. In particular, Kent coined the term conditional survival, which defines an environment where the offense defense mix creates a preemptive advantage for an attacker.[36] If an offensive first strike from an attacker can disarm the defender sufficiently such that the defenders retaliatory strike can not overwhelm the attacker's defenses, then conditional survival exists. Analysts in particular regard the situation as unstable when both sides have this capability since it creates a motive for each to preempt during crises.

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[36] Kent, Glenn and Randall de Valk. Strategic Defenses and the Transition to Assured Survival. Santa Monica, CA: RAND, R-3369-AF, October 1986.

These studies did conclude that mutual conditional survival and similar unstable mixes could be avoided through adopting particular force structure configurations that emphasize the survivability of offensive systems. For example, assured retaliation could be maintained during deployment of BMD defenses by limiting anti-submarine and air defense forces. Such actions would increase the survivability and effectiveness of retaliatory offensive forces and reduce preemption incentives.

The technical challenge of a complete strategic defense has encouraged a continuing reliance on strategic offensive forces to provide deterrence between the US and USSR. Yet, the potential for limited capability NMD systems combined with concern that potential new threats to the US in the 1990s are less amenable to an assured destruction deterrent has prompted renewed interest in defenses. The resulting environment represents a severe challenge for analysts examining relationships between strategic offensive forces, strategic defensive forces, and arms control. *How can the US maintain deterrence by punishment with some states, deterrence by denial with less potent adversaries, and still proceed with lowering arsenals?*

Underlying this discussion of possessing an effective and stable deterrent are important assumptions of what level of destruction deters a would-be aggressor. Analysts assume US and Russia require a significant second-strike capability based on all three elements of the strategic triad. Rarely do the models assume that either state would feel secure unless they maintained a force of at least 200 warheads capable of surviving a disarming first strike from the other state. China, however, has been willing to accept low force levels contingent upon a high confidence that a few countervalue strikes in retaliation to a nuclear attack would be sufficient to deter aggression. Similarly, Britain and France regard a limited countervalue deterrent force as sufficient. US NMD deployments, especially if followed by a Russian system, however, may prompt China, Great Britain, and France to regard their deterrent capability as being reduced without changes.

The second major theme is that optimal stability results from states possessing mutual and minimal offensive deterrent forces composed of highly survivable delivery systems carrying low-levels of warheads. Vulnerable (fixed-location) and high value MIRV forces encourage counterforce targeting which, in turn, can lead to tit-for-tat arms racing. In contrast, highly survivable offensive forces reduce the payoff of attacking first, thus creating a more stable deterrent. Elimination of forces vulnerable to a first strike is the most stabilizing tradeoff of stability against military capability. The same logic is used to justify hardening of missile silos. One common view is that survivable forces are necessary units, whereas vulnerable forces are considered optional, or destabilizing units. A parity of purely survivable offenses and defenses can create environments where reductions are possible due to equivalent reductions in countervalue retaliatory capability.

Yet, researchers have determined some disadvantages exist from a minimal deterrent force. First, as offensive arsenals are reduced, each individual target becomes more important. A minimal "city-busting" force may lack the credibility of potential use as compared to a counterforce arsenal, and thus erode deterrence. Also, minimal deterrent environments increase the incentive to hide forces or regenerate them quickly, and this paradigm subsequently increases the uncertainty during crises. Arms control verification becomes more important as forces decrease.

Consideration of the existing lack of parity between the US and Russia in strategic forces highlights the complication of real world issues into modeling and reduced prospects for arms control. The US has a higher percentage of deployed survivable forces, especially SSBNs. The high costs associated with converting to survivable forces dissuades Russia matching US capability. As a result, analysts seek other ways to ensure stability but see riskier means as possibly being necessary, such as allowing disparate alert levels or terms of use. This asymmetrical environment is considered less stable than a symmetrical one, and also increases outcome uncertainty by introducing a higher number of monitoring variables into an analysis.

A third major theme of the literature is that technology developments can and do dramatically affect strategic stability. Strategic stability models are highly sensitive to the accuracy of offensive and defensive forces (probability of successfully reaching or denying the target). Increasing the accuracy and effectiveness of offensive forces is generally considered destabilizing, as it reduces the survivability of a defender's retaliation force. The debate surrounding US NMD deployment is particularly sensitive to assumptions regarding technological effectiveness. IDA researchers, for example, estimate that NMD interceptor levels to combat the current threat can be as low as 30, and as high as 300, depending on the technological capabilities of the system.[37] In general, defenses of low effectiveness increase the likelihood of a successful retaliatory attack and are not highly destabilizing. Increasing defensive effectiveness actually reduces stability until defenses approach a near perfect kill rate. Highly effective defenses (>90%) tend not to be as destabilizing, since a lower, non-threatening number of interceptors can be deployed and incentives reduced. One caveat commonly mentioned is that highly effective defenses are difficult to maintain, since defensive deployment encourages countermeasure upgrades and determined offensive powers can regain the advantage. Inconsistencies among modelers often result from their assuming differing levels of technological capability and effectiveness.

Exacerbating the impact of technology on strategic stability today is radically differing capabilities of nuclear-armed states. Authors note that the disparity in US technological capability, particularly with respect to BMD, as compared to the rest of the world will require certain amount of sharing of information to prevent destabilizing reactions to US BMD deployment. Given the current faith in assured destruction, deployment of defensive forces is more likely to trigger arms racing than technological upgrades to offensive forces. Information sharing is often proposed as a solution, although there is disagreement as to whether the information shared could be perceived as credible. Unfortunately, the information most likely to mitigate the differences is information that

[37] Bracken, Jerome, James Scouras and Victor Utgoff. "Offense-Defense Strategic Nuclear Deterrent Stability Summary and Conclusions," Alexandria, VA: Institute for Defense Analysis, 1998.

is least likely to be revealed such as the actual defense technology and operational characteristics of system components.

Moving beyond purely technical dimensions of stability, researchers, especially those engaged in empirical/qualitative research, stress that perceptions of actors play a critical role in maintaining strategic stability. These perceptions include assessments of the adversary risk propensity, orientation (status quo versus revisionist), and threat credibility. For example, the credibility of using nuclear forces for extended deterrence has been a contentious subject. That is, using nuclear threats to deter an adversary from attacking allies while it can attack the state's actual homeland. Moreover, disjunction between perceptions and actual capabilities can promote tension and hamper maintaining strategic stability. Russia and China are likely to assume that US NMD systems are near perfect, even if the technology does not support the assumption. Therefore, US deployments are likely to be perceived as more threatening than they actually are, and arms racing or other reactions may occur to alleviate the perceived shift in the balance of capabilities.

Methodological Issues

Moving beyond these broad themes, researchers can produce significantly different specific findings largely as a result of four key methodological issues: assumptions, specification of the dependent variable, the independent variables included, and model complexity. Variance in assumptions does not require much discussion, but since they undergird any model or argument for that matter, the choice of assumptions has profound implications. For example, almost all of the models assume that deterrence is good and optimizing strategic stability is the goal in crises. Models that assume deterrence requires only the penetration of few warheads (minimal deterrent) as sufficient instead of a significant predetermined level of destructiveness (e.g. the McNamara threshold of a second-strike force capable of destroying 33% of the population and 66% of industry) will result in radically different outcomes.[38]

Dependent Variable

Although strategic stability is the overarching goal of the work, the measurement of the dependent variable differs somewhat among researchers. The most commonly used stability index is some variant of first strike advantage. This measure of stability compares the directional net benefits of a first strike (costs incurred from a first strike minus costs incurred from a retaliatory second strike) for both sides. It is worth noting that there is no hard and fast rule to the treatment of damage incurred/avoided. Typically, however, damage avoided costs are weighted significantly higher than

[38] Secretary of Defense Robert McNamara's threshold dates to 1965 with subsequent US officials only slightly modifying the figure as a guarantee of sufficiency against the USSR. For example, Secretary of Defense Clark Clifford in a FY1970 report raised the threshold to more than 40% of the population and 75% of industry. In a FY1979 report, Secretary of Defense Harold Brown put the requirement at destroying a minimum of 200 major cities (which would eliminate about 33% of the population and 65% of industry).

economic costs inflicted (>2 to 1). The larger the ratio of first strike advantage, the lower the stability. In the extreme case of instability, both sides would incur minimal damage if striking first, but would be decimated themselves by a first strike. Thus, there is incentive on both sides to strike first and avoid damage. A similar metric is first-strike advantage in terms of warheads surviving a first strike, instead of damage to value. Another metric is a simple measurement of the erosion of overall capability resulting from changes to strategic forces. Depending on the metric chosen, the sensitivity of stability to force changes varies and leads to somewhat different propositions of "stable" and "unstable" force configurations.

Independent Variables

Whatever researcher's definition of strategic stability, their decisions on which strategic factors to employ as independent variables enormously impacts the outcome. The following section lays out the key elements in the areas of strategic offensive forces, strategic defense forces, and threat reduction to determine the balance of capability among attackers and defenders. Significant agreement does exist on the key discriminators within each of the three core groups, but their inclusion in the assessment of strategic stability varies considerably. In particular, modelers often exclude threat reduction elements and at times focus exclusively on the strategic offensive area.

Strategic offensive forces ultimately are measured according to quantity, survivability, lethality and terms of use. In terms of quantity, the key variable that is obviously included in all nuclear exchange models is the *absolute number of warheads* available to both an attacker and a defender. Typically, baseline and evaluated scenarios take into account trends, formal agreements and intelligence forecasts. For example, models of US and Russian forces take into account proposed START reductions. Models including Britain and France assume stable forces, and models including China or regional states of concern would assume an increase in the number of warheads, when evaluating future environments. Some high-resolution models allow for the introduction of a time variable or *reconstitution rate* to account for generation of forces during crises or war. Reconstitution rate, however, is not typically viewed as a critical variable for strategic planning, with the exception of very low force level scenarios.

In addition to warheads, the models also account for the diversity of delivery systems. Typically an *absolute number of distinct delivery systems* is measured and the characteristics of each delivery system is assumed. *Warheads per missile, warheads per silo/bomber,* and a measure of *reload capability* are commonly used to quantify the number of warheads available for use.

Another key variable affecting the performance of strategic offensive force capability is a measure of *survivability* or *vulnerability* of the warhead. Typical inputs that affect survivability are *base hardening*, *mobility* and *alert status*. Mobile ICBM launchers, deployed submarines and bombers, for example are considered untargetable and relatively invulnerable to a counterforce attack. The dispersion of bases, redundancy of silos and location of warheads relative to an attacker's range can also be factored into survivability calculations.

Most, but not all, models also include a measure of warhead *lethality*. Lethality can be loosely defined as the effectiveness of a warhead in arriving and inflicting damage to the intended target. The most commonly used factors affecting lethality are the *number of penetration aids and their effectiveness against defenses* and *weapon accuracy (CEP). Warhead size (MT)* can be used to scale damage costs, although only the highest resolution models include a measure of size in strategic models.

Finally, offense exchange scenarios will frequently incorporate a measure of *retaliatory terms of use* to evaluate offensive capability. *Launch policies* of Launch Under Attack, Launch on Warning (generally viewed as undesirable) or Ride Out Attack affect the survivability of weapons. *Targeting criteria* affects the lethality and damage inflicted. As an example, highly survivable warheads would most likely target countervalue locations, but vulnerable forces might only target vulnerable enemy counterforces.

Strategic defensive capability is similarly measured according to quantity, survivability, effectiveness and terms of use. The *absolute number of interceptors* is the primary variable associated with quantity. In recent years, several models have assessed the minimum amount required to combat a 5-20 warhead threat from an accidental or unauthorized launch. The *type of interceptor* can also be modeled. Several models incorporate boost, midcourse and terminal interceptors into a layered defense.

Defense *survivability* and *vulnerability* is not always added as a variable in offense-defense models. However, inputs have included *base dispersion* and *hardening.*

Perhaps the most critical variable when analyzing strategic defensive forces is the *effectiveness* of the system. The probability of intercepting an attacking missile is related to the *warning time,* particularly important for boost phase, *hit to kill percentage* and *countermeasure discrimination percentage,* also referred to as warhead tracking percentage. Since BMD technology is maturing, assumptions pertaining to defensive system effectiveness are likely to change as tests provide insight into potential performance capabilities. Another possible variable is the BMD *deployment scheme.* The decision to deploy a single or multi-site system affects the probability that defenses can thwart an attack.

Terms of Use also affect the performance of strategic defensive forces. The most important factor affecting this variable is the *firing doctrine.* Shoot-Look-Shoot doctrines would be more efficient and require fewer interceptors per warhead. However, technical limitations would most likely limit the firing doctrine to less efficient Barrage firing in the near term.

The effects of threat reduction measures are not well quantified in the literature, although an abundance of works debate the theoretical costs and benefits of various threat reduction initiatives. The political value of arms control agreements is difficult to quantify, but the effects of *verification* and its impact on uncertainty has been widely discussed and modeled in a few instances.

Analysis has also been conducted on the effectiveness of confidence building measures, particularly in relation to the risks of violation. *Dealerting* and *demating* of a certain percentage of weapons, although widely touted, has generally been analyzed in the context of minimizing the instability theses measures tend to produce. The success of other threat reduction measures, such as shared early warning and cooperative programs, are typically evaluated using a simple cost/benefit analysis.

Complexity

Models differ significantly in complexity and resolution with the result that findings can vary considerably. The norm tends to be simple models, characterized by more assumptions and less interactions among the variables. For example, some models use kill percentages that are based on the worst case/best case planning perceptions of an attacker and defender. More resolute models include a probabilistic calculus, whereby kill percentage and confidence levels vary based on the exchange parameters and attack sophistication. Similarly, targeting and alert status assumptions vary with the complexity of the model. Targeting can be static (predetermined percentage of counterforce/countervalue) or a dynamic algorithm based on intentions and capabilities. Defensive forces can also vary from simple random subtractive calculations (defenses destroy a given percentage of offensive weapons) to adaptive calculations (finite defenses selectively concentrate on destroying incoming warheads with highest target values).

Conclusions

This brief literature review has examined the substantive findings and methodological approaches of researchers seeking to understand how to achieve strategic stability. As noted in the beginning, it has concentrated on deductive, modeling efforts to lay the foundation for the development of the model at the end stage of this project. Yet, the study team has familiarized itself with the other approaches that undergird modeling efforts, both inductive studies and deductive arguments, to facilitate model development. With regard to the current state of play, the study team has come to the following conclusions:

- Threat reduction generally appears not to have been modeled as an explicit component of evaluating strategic stability. Some efforts to consider aspects such as how force posture affects a situation have been calculated, but researchers predominantly assess offense-offense and offense-defense tradeoffs.
- The vast majority of work evaluates dyads (essentially the US versus the USSR), while multipolar modeling is in its infancy. The reduction of US/Russian arsenals, the growing lethality of China’s nuclear forces, and the horizontal proliferation of nuclear weapons suggest that in the future multipolar models will be of increasing necessity.

- Technological and political conditions are increasingly dynamic requiring more sophisticated models, especially as the US pursues alternative deterrent strategies vis-à-vis different adversaries. Moreover, actors in a deterrent relationship may posses contrasting strategic cultures, which can significantly impact on leaders' calculations and behaviors. Such a consideration typifies the need for greater sophistication than required during the Cold War.

Sources employed in Task 3.3 Database

The project team built a database to needed to run the model, employing several sources.[39] The cost data currently part of the data was generated for development purposes and should be regarded as preliminary. Weapons costing is a complex process, and is an area where disparate methodologies exist that produce wildly different numbers. In addition, unclassified cost data for Chinese and Russian forces is not readily available, and perhaps not even applicable. Further work to develop a coherent, consistent database is probably required before the cost numbers produced by the model can be regarded as fully credible. The figures in the current database are mainly meant to illustrate model functionality.

[39] Firth, Noel E. and Noren, James H., *Soviet Defense Spending* (College Station: Texas A&M Press, 1998); Graben, Eric K., *What Don't We Need Anymore* (New York: University Press of America, 1992); Schwartz, Stephen I, Editor, *Atomic Audit* (Washington: Brookings, 1998); USAF Factsheets, http://www.af.mil/news/factsheets.html.

APPENDIX C:
Users Guide to the "SODA Machine"

This model is designed to mathematically calculate the feasibility of changes in a country's strategic force structure, assessing if and how deterrence factors into the decision to build or reduce arms. This model allows you (the Blue player) to create and run scenarios based on offensive and defensive forces. You can choose to compete against one or two opposing forces, either Red, or Green, or both Red and Green. Each turn allows the countries to build or reduce their number of forces for a given time period. You will choose the force levels for Blue, and the computer will play the roles of Red and/or Green. At the end of each turn, you will receive a summary of the actions taken by the countries, and can focus your attention on the impact of altering a key input.

Getting Started:
Insert the disk or CD into your computer. Click on My Computer. Click on either the A; drive, or your CD. You will be asked whether you want to open the application or save to disk. Select Save. Save to either the C: drive, or your personal drive. This will allow the application to run more quickly than running it from the disk. Select both the Excel Spreadsheet and the Database and Save them.

Open Excel and select the DTRA spreadsheet. You will be asked to Disenable or Enable Macros, Select Enable Macros. You will then be asked which database to use, the DTRA database will be highlighted. Click OK.

The model will open showing the DTRA logo and a series of button options: scenario, treaty, posture, criteria, offense, defense, and doctrine. Note that the treaty button is not active at this time.

If you exit out of this screen, you can return to it by going to the "tools" button on your Excel tool bar and select DTRA.

Scenario:
This option is used to review or build a new scenario game.

Select the Scenario Button

Scenario Options

New

Click this button to create a new scenario. Once the button is clicked, a dialog box will prompt you to enter a name. Enter a name for your scenario, then click OK. A force posture screen will appear. This screen will let you choose the forces for Blue, Red and

Green. It also gives you the option to choose an arms control regime. This limits the forces in accordance with particular treaty regulations.

On the right are three input boxes: Competition, Start Year, and Turn Duration.
Competition: You choose the players in the scenario Blue vs. ____.
Start Year: You choose the year the game starts.
Turn Duration: Allows you to dictate how long each game will be played. Currently a default is set at five years, meaning, the time allowable to build the force structure you dictate will be five years. For example, if you chose 2000 as the Start Year, the end of the turn will be 2005.

Force Posture:
You may choose an existing force posture by clicking on the draw down box next to the player. There are several listed. Highlight the one you would like, and it will take you to another screen with posture options. If you choose, you can create a new posture. Click New and the same force posture options will appear.

The options for this screen are: Criteria, Offense, Defense, and Doctrine, each with the option to create new, edit or delete.

Criteria:
The first option is criteria. This screen allows you to input GDP data on a force and determine the amount of military spending. You can choose GDP profile, which gives you growth options, such as 3%, flat, etc, or you can choose GDP file, which allows you to access a database (to be created by the user) of past and present actual GDP figures.

GDP 1000000

This field indicates the Gross Domestic Product for the current player at time zero, which in most cases is 2001.

GDP Profile

Flat
Rise 3%
Flat 10 turns, then rise 2%
Rise 5% 10 turns, then rise 3%

The GDP Profile selected indicates how the GDP changes from year to year.

Norm Max GDP 4.5 ***%***

The player cannot exceed the normal maximum if its security requirements are met.

Abs Max GDP 4.5

The player cannot exceed the absolute maximum under any circumstances.

Under the GDP options there are three sections: Guaranteed Retaliation, Averted Loss and Effective Balance. Each cell in this section corresponds to a cell on the master Excel spreadsheet. You may enter a value that you want to set in any of these cells and it will be automatically transferred to the main spreadsheet.

Offensive Forces:
The next option is to edit the offensive forces. You can choose Land, Sea or Air based systems. You have the options to add, edit or delete any of the offensive forces. To view forces, click on the edit button. The prompt will ask you if you want to edit forces structure, click OK. You will see a list of your offensive forces with the number of platforms, warhead, etc. If you choose to keep this structure click OK, if you would like to add, click the Add button. A list of systems will appear, click on the system you would like to add. After you add a system, that system will no longer be available to add, you may however make changes to the system at any time by highlighting the system and clicking the edit button.

To edit the existing force structure, highlight the system and click the Edit button. Make the adjustments to the system and click OK. If you would like to delete a system all together, highlight the system and click Delete.

To return to the Posture page hit OK.

Defensive Forces:
The next option is the defensive forces. Each player has the ability to add, remove and edit boost-phase, midcourse and terminal defensive systems.

To edit an existing interceptor type, the user highlights the interceptor type of interest and clicks the “Edit” button directly below the current list. The user is then prompted to enter a value for the number of interceptors and the percentage of max expendable interceptors/raid.

To add an interceptor type, the user clicks the “New” button beneath the section corresponding to the flight phase of interest. For example, clicking the “New” button in the Boost-Phase section brings up a list of the available “Boost-Phase” systems for this force structure. The type of affiliation (“BLUE”, “RED”, “GREEN”) associated with this force structure and displayed in the “Affiliation” section of the form limits the system types available to this force.

To remove an interceptor type from the current force structure, the user highlights the interceptor type of interest and clicks the “Delete” button directly below the current list.

If the force structure contains data from multiple turns, the data from each turn is displayed by selecting the corresponding turn number in the lower right section of the form.

To save the changes made to the force structure, the user clicks on either the “Save” or “Save As” buttons.

Doctrine:
This field allows you to set the military doctrine in terms of readiness, and retaliation parameters. You may input a number directly in the boxes for the first 4 items. The remaining options have a draw down box to select alternatives.

Edit

Click this button to edit a scenario.
Click the Edit button.
You will see several options listed. Three fundamental scenarios: Blue vs. Red, Blue vs. Green, and Blue vs. Red and Green
You will also see previous scenarios that were developed each with its own date stamp.

To build on one of the three fundamental scenarios, highlight that scenario and click on the edit button. This will open a force structure window for each member of the scenario, blue, red and green.
Follow the directions above under Force Posture.

Delete

Click this button to delete a scenario. Scenario components and sub-components such as posture, criteria, force, etc. are not deleted.

Run

Click this button to run a scenario. A discussion of the user forms that are generated during runtime occurs in the “Running a Scenario” section of the document.

Del Results

Click this button to delete a scenario and its underlying components. This is used primarily to delete results from a previously run scenario. A scenario with a time stamp appended to the end of the name usually indicates a scenario with run results.

Replay

Click this button to replay scenario results. A discussion of the user form that is generated during runtime occurs in the "Replay Results" section of the document.

Running a Scenario
Once the run button is clicked, the model does the following:

1) Read in all scenario data from the database and create data structures corresponding to the database tables and fields.

2) Format a spreadsheet with the scenario data and the formulas used to calculate everything.

3) The built-in Solver optimizer attempts to come up with a new mix of forces for BLUE that satisfies all constraints, meets thresholds and minimizes cost.

4) The Solver-generated results are displayed, at which point the user has the option of accepting these changes or modifying the force structure him/herself.

System Database – clarification of terms

SystemName – Name of the offensive/defensive system type.

PlatformName – Name of the platform upon which the missile/interceptor resides.

MovementType – For an offensive system, this field can be Land-Based, Sea-Based or Air-Based. For a defensive system, this field can be BoostPhase, Midcourse or Terminal.

ForceType - Designates whether the system is Offensive or Defensive.

Yield – Applies only to offensive missile systems.

CredibleDecoysPerWH - Applies only to offensive missile systems.

Survivability - Applies only to offensive missile systems.

LaunchReliability - Applies only to offensive missile systems.

DetonationReliability - Applies only to offensive missile systems.

WHperSNDV - Applies only to offensive missile systems.

SNDVperPlatform - Applies only to offensive missile systems.

CostRandD – Research and Development Cost

CostP- Production cost

CostOandM- Operation and Maintenance Cost per year

PlatperBase - Applies only to offensive missile systems.

CarrierPenFactor - Applies only to defensive missile systems.

BuildTime- Length of time to build one platform

AvailabilityBlue - The year at which this system type is available to Blue. 9999 indicates never.

AvailabilityRed - The year at which this system type is available to Red. 9999 indicates never.

AvailabilityGreen - The year at which this system type is available to Green. 9999 indicates never.

Bases: The variable bases is used to determine how many warheads must be allocated to attack bombers and submarines that are not on patrol, airborne, and will be unable to put to sea or take off before the incoming warheads arrive. The variable assumes bombers and submarines not on patrol, airborne, and will be unable to put to sea or take off before incoming warheads arrive are concentrated on bases, so that a single warhead might kill large numbers of them.

Averted Loss: Averted Losses measures the difference in the damage a side will suffer if it is the second striker during a nuclear exchange, as opposed to if it goes first. For any of the turns, this measure if of the potential capabilities of both sides – no exchanges are actually carried out. Averted Losses also applies strictly to that potential nuclear exchange. It is not a measure of the damage averted by changing force structure from turn to turn.

Boost Phase: Boost phase applies only to ballistic missiles. It covers that period between launch and when warheads and pen-aids are deployed. The boost phase model is very simple. The size of the ballistic attack modified by a defense coverage factor is compared to the amount of boost phase inventory to determine how many boosters are engaged. Based on a probability of kill, some of these boosters, and their warheads are removed, and the remainder proceeds through subsequent defense layers. Note that the methodology is not completely suited to lasers, given the amount of resources used during each phase would vary from missile to missile, due to range, type and sequencing factors. Also note that the model assumes all warheads and pen-aids are released instantaneously – no kills of partially loaded buses are modeled.

Retaliation Alert Rate: The model presumes that if a side determined that it was going to initiate nuclear war, it might bring its forces to a hyper state of readiness even higher than the “fully” generated rate it might operate at during times of heightened alert.