Attribute Tradeoff Model (ATOM)

Model and Software Documentation

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Introduction

Given New Start, the Administration's interest in "nuclear zero" and a budget-constrained environment, analysts are likely to receive greater numbers of requests for comparison of the capacity of various force postures and structures to achieve nuclear policy goals. At present, no theoretically grounded and systematic method exists for comparing how well specific (attribute-based) force postures support specific policy objectives. In the nuclear context, the central policy objectives identified by the Concepts and Analysis of Nuclear Strategy CANS project[1] are strategic stability, counter proliferation, deterrence, assurance and defeat.

ATOM relies on an assessment process that first analyzes a problem structure from complex concepts to more basic and directly measurable elements and then synthesizes the evaluation of those basic elements through the structure so that alternatives may be assessed not only on the basics, but on the high-order concepts as well. The first challenge raised by this task is determining how to link discrete and measurable force posture attributes (such as flexibility, sustainability and reach) to such broad concepts as deterrence and counter proliferation in a systematic and meaningful way. ATOM achieves this by creating a theoretical model that decomposes these high-level policy objectives into their basic elements, and then links individual force posture attributes to these specific elements (see Figure 1). The theoretical model draws on an extensive academic and policy literature to determine the set of elements for specific policy objectives.

The second challenge is to derive assessments with respect to high-level concepts such as policy objectives from the evaluation of the more basic elements of the model decomposition such as force posture attributes. There are many algorithms designed to aid in this process—what is often referred to as multi-attribute decision analysis—and ATOM includes two that have been instantiated into its software. A fuller description of these algorithms appears below in the ATOM Software Overview section of this document.

The ATOM software is composed of two parts: (1) a Java-based Structure Authoring Tool that provides users a graphical interface for decomposing the problem space and; (2) An R-based Decision Support Engine (DSE) that aggregates the assessment of force posture alternatives through to policy objectives, cost and risk. In essence the software takes the model and represents it graphically in the form of tree diagrams that clearly map the breakdown of individual policy objectives and the link between policy elements and force posture attributes. This relational information is then used by the DSE to assess the relative strengths of specific force postures for achieving individual or multiple policy objectives.

[1] The Concepts & Analysis of Nuclear Strategy (CANS) project undertaken for US Strategic Command (USSTRATCOM) was tasked to examine the utility of alternative analytic techniques for assessing nuclear force attributes and sufficiency under a variety of changed conditions.

ATOM, as presented in this guide, therefore, should be thought of as two related, but distinct products. The first is the theoretical model, which is specific to the nuclear policy context; the second is the software, which, although developed to deal with this specific model, is in itself content-free. The Structure Authoring Tool and DSE can be used to render a detailed decomposition and analysis of any problem space of interest to the analyst, from nuclear policy to which motorcycle to buy. It is our expectation that for analysts interested in the nuclear policy problem space there will be very little need to change the current instantiation of the theoretical model. Two possible exceptions to this would be modifications of the edge weightings (which are currently all set at 1.0, implying equal weighting of each child node) and additional linkages between specific policy elements and force posture attributes. The majority of input will be done in the DSE, with the comparison of specific force postures (represented by their ratings across the 13 meta attributes taken from STRATCOM's existing analysis structure) across different combinations of policy objectives.

ATOM Nuclear Policy Space Model

The ATOM nuclear policy space model starts by identifying the top level components of US nuclear policy most commonly referred to in policy and doctrine: deterrence, assurance, defeat, counter proliferation and strategic stability. For the purposes of this model, however, further refinement of these objectives was necessary. First, strategic stability and counter proliferation are considered as higher-level goals, achieved through the application of a specific policy: deterrence, assurance or defeat. Furthermore, policies of deterrence, assurance and defeat are considered in the policy and academic literature to be context dependent and thus, must be further defined. Deterrence or assurance designed to counter proliferation have different requirement dimensions from those of deterrence or assurance for strategic stability. It is also clear from the academic literature that deterring an attack against one's own territory is a different problem from deterring attack against a third party. Finally, policy statements and concept papers make a clear distinction between defeat designed to neutralize an opponent's military capability and defeat with the intent to destroy. To these refined policies were added cost and risk, which figure prominently in the DO JOC and are intrinsic to STRATCOM's current analysis process.

Nine top level nuclear policy components:

1. Direct deterrence
2. Extended deterrence for strategic stability
3. Extended deterrence for counter-proliferation
4. Assurance for strategic stability
5. Assurance for counter-proliferation
6. Defeat (neutralize)
7. Defeat (destroy)
8. Cost
9. Risk

The ATOM model starts by mapping the disaggregation of individual policy objectives, then linking, where possible, individual force posture meta-attributes to those elements. The alternative approach would have been to start with the list of force posture meta-attributes and determine how these may influence specific aspects of a policy objective. This is significant, as it means that the ATOM model includes policy elements that are not (as far as we know) directly affected by force posture attributes. Thus, the model tells the analyst not only where force posture can make a difference to achieving a policy objective, but also where it cannot. This can be of particular interest in situations where tradeoffs between policy objectives arise. Figure 2 illustrates the complete ATOM nuclear policy space model. The inner circle (blue) comprises the nine top-level components, the next ring (red) are the policy dimensions, the third ring (green) the elements of those dimensions and the outer ring (white) the force posture attributes associated with specific policy elements.

The rationale behind the disaggregation and specification of each of these policy components will be discussed next. This discussion is not an exhaustive review of the literature behind the ATOM model; rather, it is intended to walk the user through each branch of the ATOM hierarchy. A brief definition of each policy objective is given for each branch, then an explanation of how each of its component dimensions and elements are defined. The primary purpose of this explanation is to ensure that the analyst has a clear understanding of the scope of explanation that the ATOM nuclear policy space model incorporates. Once the theoretical component of the model is explained, the logic behind the connection of the force posture meta-attributes (see Table 1) to the theoretical portion of the model is discussed. This will then enable the analyst to better interpret the evaluations of force postures generated by the software and place their analysis within a strong theoretically driven policy problem space.

NOTE: Reading the ATOM Model Diagrams

Names of all entities comprising the ATOM nuclear policy space model are unique. That is, if a dimension or element appears in more than one place in the model, it is defined in exactly the same way. So "credibility" is decomposed the same way in the deterrence branches and the assurance branches (see Figures 3-7). If a general concept is defined differently depending on the policy objective or dimension it is related to, this is reflected in the naming of that dimension or element. For example, as discussed below, the requirements for credible extended deterrence are different from those for credible direct deterrence. Therefore the name of the dimension includes the related policy objective (see Figures 3-5).

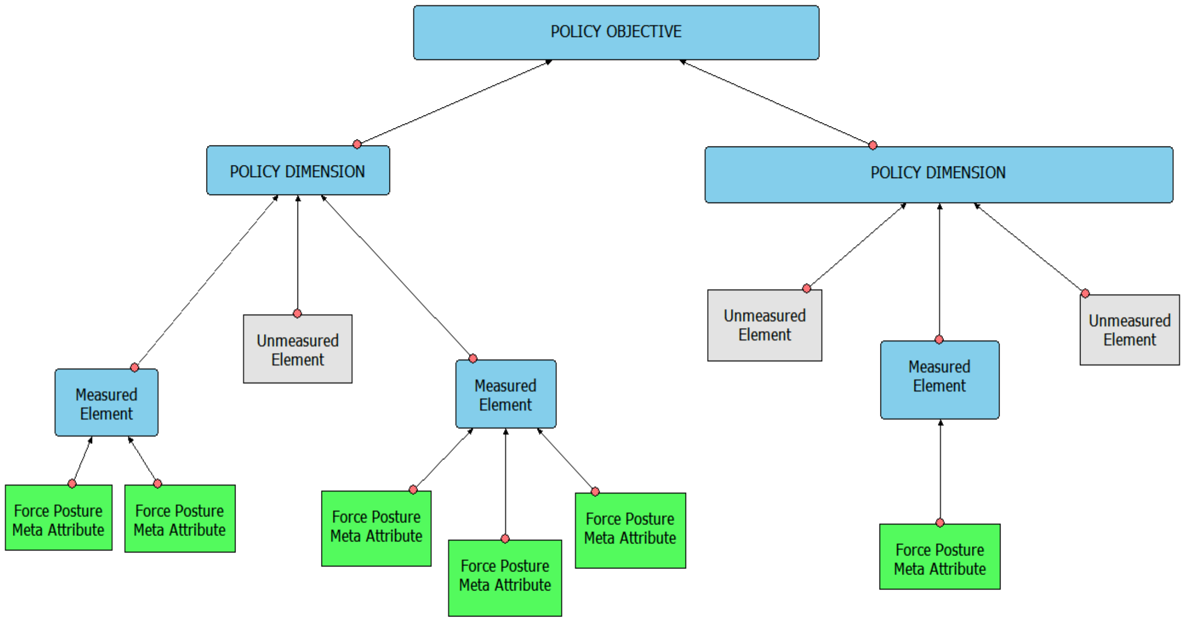

Figure 1. Hierarchical structure of ATOM model

NOTE: Interpreting the results generated by the DES

The ATOM model is designed to examine how well a specific force posture can contribute to a set of policy objectives, relative to other possible force postures. While the theoretical model is fully specified at the conceptual level, it is not fully operationalized. The only measured attributes that are incorporated into the DSE assessments are those relating to force posture. This is a critical distinction for the analyst to keep in mind when interpreting the results generated by the DSE. These assessments indicate how well a particular force posture can contribute to a specified set of policy objectives. It is not an overall assessment of how well the US will be able to achieve its policy objectives. Since the ATOM theoretical model includes attributes that are external to force postures, future implementations of the ATOM model may include estimates of values on these attributes to study how exogenous factors may bear on the way different force postures are ultimately assessed.

Direct Deterrence

We begin by specifying a model of the simplest form of deterrence: direct deterrence. Direct deterrence is a policy directed at preventing an armed attack against one's own territory (Huth & Russett, 1988; Huth P. 1999). US–Soviet relations during the Cold War is an example of direct deterrence. Figure 3 below shows the direct deterrence model diagrammed in the ATOM Structure Authoring Tool. Capability, credibility and communication are the only three dimensions identified as critical to direct deterrence.

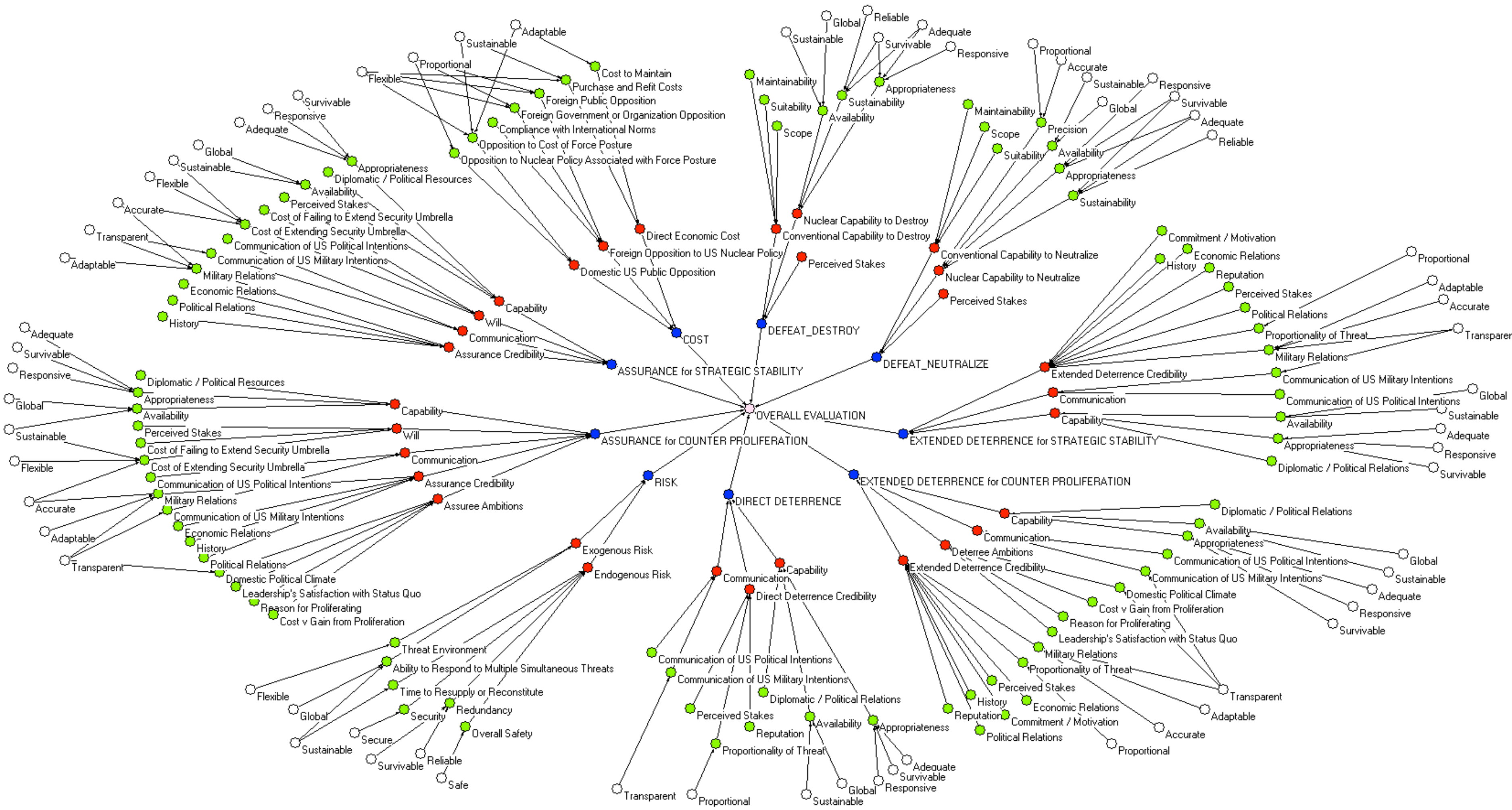

Figure 2. Entire ATOM nuclear policy space

Capability

Capability refers to the ability and actor to make good on its deterrent threat or promise of assurance. Capability is closely linked to credibility, but most theorists treat it as a distinct higher-level concept, as is done in ATOM. Capability is decomposed into three component elements: Diplomatic and political resources, Available military capabilities and Appropriate military capabilities.

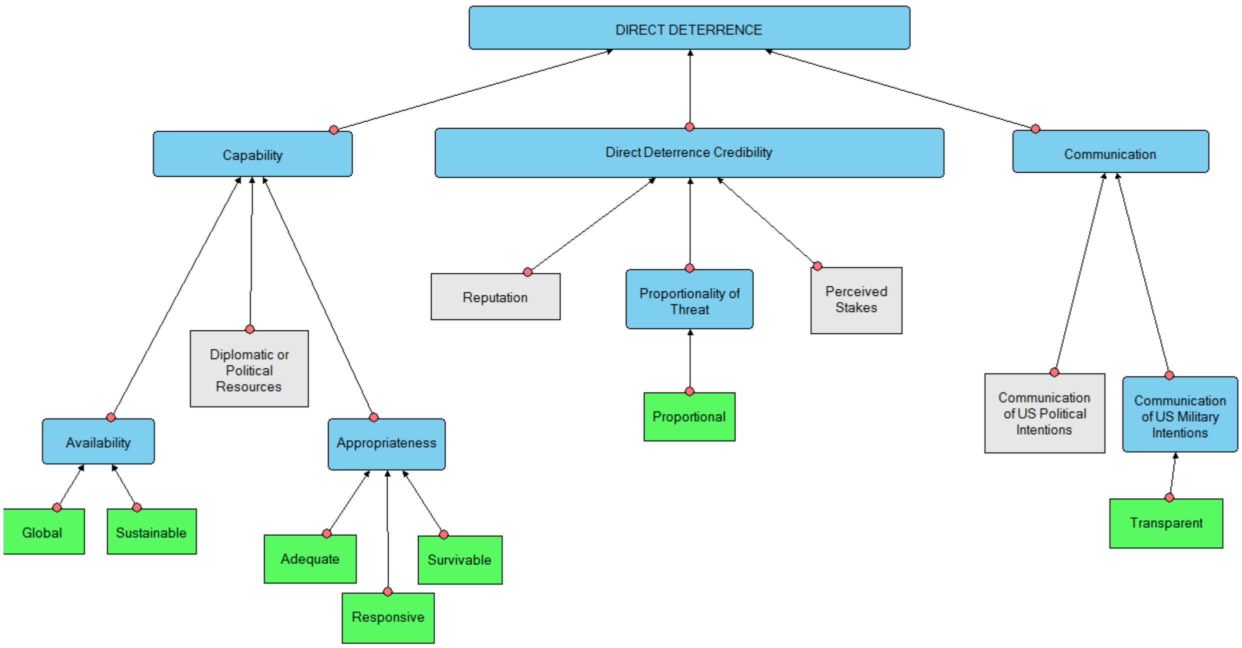

Figure 3. ATOM Structure Authoring Tool — Direct Deterrence

Diplomatic and political resources captures the non-military aspects of the US's ability to put pressure on another actor. Specifically, diplomatic and political capability to resolve a dispute or potential crisis increases capability by decreasing the reliance on military force alone.

Linkage to force posture: none

Appropriateness of military capabilities: If a threat is to be effective, the target of the threat must believe that the actor has the military capability to carry through on the threatened action. One aspect of this capability is the possession of nuclear forces capable of taking the threatened action. That is, the capability must be perceived to be consistent with the threatened response to non-compliance.

Linkage to force posture: Direct: adequate; responsive; survivable

Responsive force postures can rapidly change alert status or location. Adequate force postures provide target coverage and weapons sufficiency. Survivable force postures increase the probability that US weapons will penetrate enemy defenses.

Availability of military capabilities: Particularly in the post-Cold War era the US faces threats from multiple different state and non-state actors. Therefore, when considering the capability of a US deterrent threat or promise of assurance, it is crucial to take this wider context into consideration. Not only does the US need to possess the appropriate capabilities to respond to non-compliance, it also needs to be able to signal that these capabilities are not otherwise committed. The greater the overall extent of US security commitments, the less likely it is that the US will be able to convincingly signal availability of military capabilities.

Linkage to force posture: Direct: global; sustainable

Global force posture coverage can protect an ally against threats from any geographic location. Sustainable force postures are both more affordable and more available.

Communication

No matter how capable the US may be, or how credible its threat, if the intended target is unaware that the US seeks to deter them, they will not know to adjust their decision calculus to account for the threatened retaliation. Put more simply, to be effective a threat must be communicated. This implies not only that the intended recipient receives the message, but also that it interprets in the manner intended.

Communication of US political intentions: Studies examining crisis bargaining behavior suggest that both the military and diplomatic actions of the deterring actor have significant effects on the outcome of immediate deterrence. A uniform finding is that consistent, clear messaging assists in reducing miscommunication, improving the outcome of deterrence or assurance policy (Leng, 1993; Fearon, 1994; Posen, 1991).

Linkage to force posture: none

Communication of US military intentions: Rational deterrence theorists have argued that "costly" signals are required to communicate credibly a defender's resolve (Schelling 1966; Jervis 1970; Powell 1990; Nalebuff 1991; Fearon 1994a, 1994b, 1997). That is, some demonstration of military intention, rather than just words.

Linkage to force posture: Direct: transparent

Transparent force postures provide physical evidence and confirmation of US intentions.

Direct Deterrence Credibility

Credibility is perhaps the most complex concept underlying both deterrence and assurance. The success of both policies is as much a function of perception as it is reality; the target of the policy (assurance or deterrence), must believe the threat in order for it to be effective. In the strategic literature, credibility has usually been taken to be synonymous with believability (Schelling 1966; George and Smoke 1974; Freedman 1981; Jervis 1985).

Perceived Stakes: The importance of the issue at stake to the actor is considered a crucial element of credibility. According to rational deterrence theory, in order to be credible, the threat must have "demonstrable or reasonable relationship to the maker's real national interests" (Craig & George 1995). The contention that positive utility is a necessary requirement for conflict initiation has also been demonstrated in the rationalist explanations of war (Bueno de Mesquita 1981), and supports the contention that for a threat to be credible, the issuer must have a positive utility for acting on that threat.

Linkage to force posture: none

Reputation: In 1966 Schelling proposed that "what one does today in a crisis affects what one can be expected to do tomorrow" (1966: 93). Both the domino theory and the Brezhnev Doctrine were based in large part on the logic of reputation, yet many US and Soviet officials and analysts felt great trepidation when confronted with intervention on those grounds (Long 2008: 14). Despite policy and academic hesitation regarding the wisdom of tying actions in one context to outcomes in another, this continues to be a common thread in deterrence and assurance actions. This argument is frequently brought forth to support both action and inaction in foreign policy crises.

Linkage to force posture: none

Proportionality: Successful deterrence is partly a function of the relationship between credibility and the potency of threat. If a threat is too strong, it will lack credibility. If threat is not strong enough, it will be credible without changing the cost-benefit calculation of the target (George & Smoke 1989: 177).

Linkage to force posture: Direct: proportional

Force postures that allow for proportional responses increase credibility both directly, and by decreasing the domestic and international political blowback that may otherwise inhibit use.

Extended Deterrence for Strategic Stability

The practice of third party deterrence, or protection of an ally or client state (Huth & Russett, 1988: 2), formed a crucial element of security policy for Western powers in the Cold War era. The underlying assumption of the concept is that major power states have security interests beyond their borders, and that extended deterrence is an expression of such interests. (George & Smoke, 1974; Huth, 1999; Huth & Russett, 1988; Lebow & Stein, 1994; Russett, 1963; Stein, 1996; Weede, 1983; Wu, 1990; Zagare & Kilgour, 2000). Extended deterrence differs from direct deterrence primarily in the requirements for credibility. As Schelling recognized early on, "the difference between the national homeland and everything 'abroad' is the difference between threats that are inherently credible, if unspoken, and the threats that have to be made credible" (1966, p. 36).

Capability

See capability discussion on page 9 under direct deterrence.

Communication

See communication discussion on page 10 under direct deterrence.

Extended Deterrence Credibility

Perceived Stakes: see perceived stakes discussion on page 11 under direct deterrence credibility.

Reputation: See reputation discussion on page 11 under direct deterrence credibility.

Proportionality: See proportionality discussion on page 11 under direct deterrence credibility.

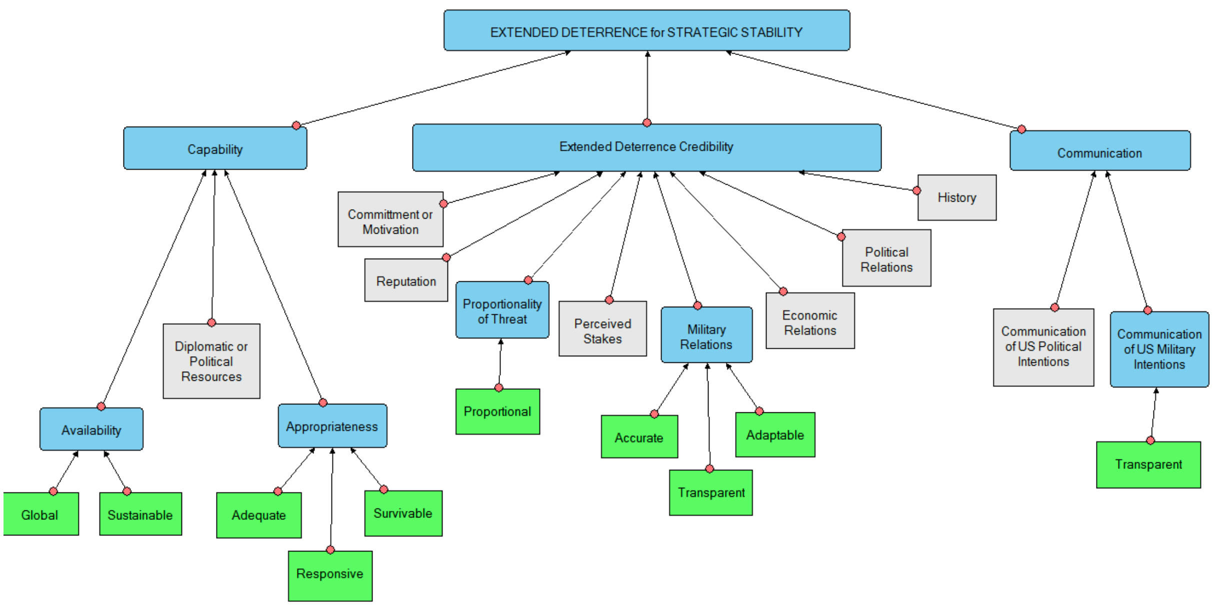

Figure 4. ATOM Structure Authoring Tool — Extended Deterrence for Strategic Stability

Commitment / motivation: As discussed above, credibility in an extended deterrence context is harder to achieve. One signal of motivation can be treaty obligations that formalize and make public one state's commitment to the other. These can take the form of military alliances or more specific pledges of military support given to an ally.

Linkage to force posture: none

Political relations: The credibility of a military commitment to a third-party can is more likely to be regarded as credible if there are strong and demonstrable ties between the two parties. Formal alliances and strong common interests are both factors that increase the potential cost to the US of losing an ally.

Linkage to force posture: none

Economic relations: National interest has an economic as well as security dimension. The existence of trade agreements and the level of economic interdependence between the US and the ally it is seeking to protect (through a policy of assurance or deterrence) can be a strong signal of national interest. Similarly, economic investment in the form of development or humanitarian aid can also increase the perception that the US has interests at stake that rationalize acting on their threat.

Linkage to force posture: none

Military relations: US involvement with an ally's military can take the form of training, basing of troops and weapons, or shared technology. All of these activities send a "costly signal" (Schelling 1966; Jervis 1970; Powell 1990; Nalebuff 1991; Fearon 1994a, 1994b, 1997) that the US is resolved to defend an ally.

Linkage to force posture: Direct: accurate; transparent; adaptable

Adaptable force postures increase the probability that allies will have experience with US systems, making cooperation easier. Transparency provides evidence that the US has plans in place and resources to implement them, increasing trust. Accurate force postures increase the probability that an opponent will incur damage, increasing their costs of conflict.

History: The political, military and economic relations elements of credibility capture the current relations between the US and an ally. The duration as well as the extent of these relations contributes to the credibility of the US threat to defend. In particular, prior military or political interventions are strong signals of both interest and resolve.

Linkage to force posture: none

Extended Deterrence for Counter Proliferation

In the counter proliferation context the ambitions of the deterree become a critical determinant of deterrence success or failure, as they are so commonly linked to important domestic political considerations that are resistant to US threats.

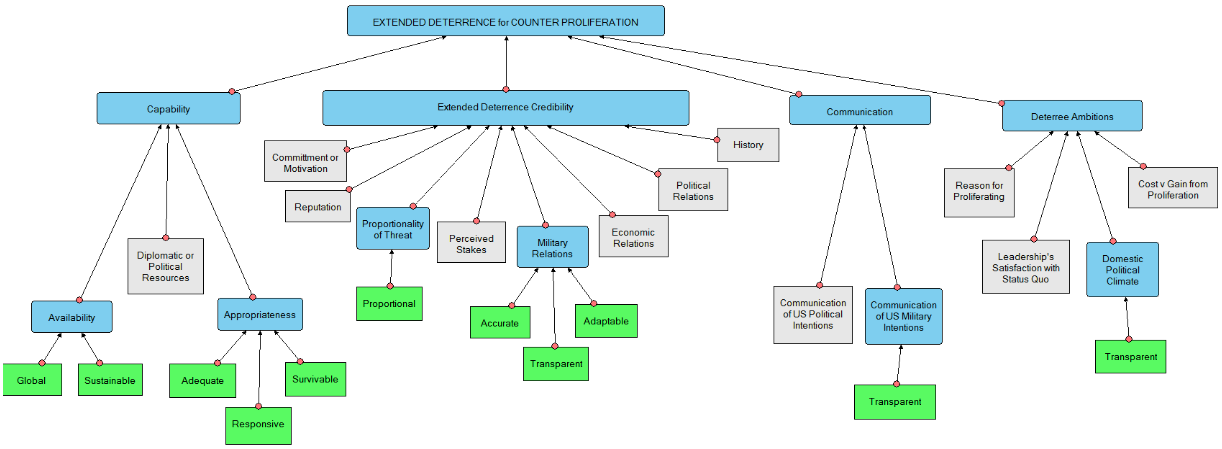

Figure 5. ATOM Structure Authoring Tool — Extended Deterrence for Counter Proliferation

Capability

See capability discussion on page 9 under direct deterrence.

Communication

See communication discussion on page 10 under direct deterrence.

Extended Deterrence Credibility

See extended deterrence credibility discussion on page 12 under extended deterrence for strategic stability.

Deterree Ambitions

Reason for Proliferating: There are various reasons why states seek nuclear weapons capability. Among the most common are national security, offensive power, and national prestige. If offensive power is the motivation for proliferation, it is possible that the proliferator will be deterred by the threat of punishment. If, on the other hand, a state seeks nuclear weapons for national prestige, it is less likely to be deterred.

Linkage to force posture: none

Leadership's satisfaction with the status quo: States that benefit from their position in the international community stand to lose more if they take actions that generate opposition from major powers than do autarkic or "rogue" states and thus will be easier to deter. When the leadership of a state feels that its influence in the international community is not appropriate to its perceived importance, they are more likely to resist losing any element of their relative power, and more likely to attempt to increase that power.

Linkage to force posture: none

Domestic Political Climate: States that are increasing in size and economic power often face a deficit in international prestige that is felt not only by leaders but also by the public. All major powers in the post-World War II era have been nuclear powers, and states with nuclear weapons capabilities are often seen to have greater political clout than others. Leaders of states that seek to increase their international profile sometimes bolster their domestic popularity by starting nuclear weapons programs. When there is popular support for a state becoming a nuclear power, either for reasons of security or prestige, leaders who surrender to a US threat face significant loss of face that may well lead to a loss of power.

Linkage to force posture: Direct: transparent

Transparency provides evidence to support US stated intentions. This can increase trust and decrease uncertainty, reducing the security motivation for the pursuit of nuclear capability.

Cost versus gain from proliferation: Nuclear weapons programs are economically costly, both directly (research and development) and indirectly if sanctions are imposed by the international community. Just as there are domestic political costs associated with ending a weapons program, there are also international political costs associated with its continuation. Loss of international diplomatic connections and regional destabilization can result from a state's pursuit of nuclear weapons.

Linkage to force posture: none

Assurance for Strategic Stability

In the nuclear realm assurance is closely tied to notions of extended deterrence and manifest in defense pacts and other international security arrangements. That is, if our allies find our extended deterrent threat (as it pertains to potential attacks against their territory) to be credible, and believe that their opponent (the target of the deterrent threat) believes the threat to be credible, and the ally will feel assured.

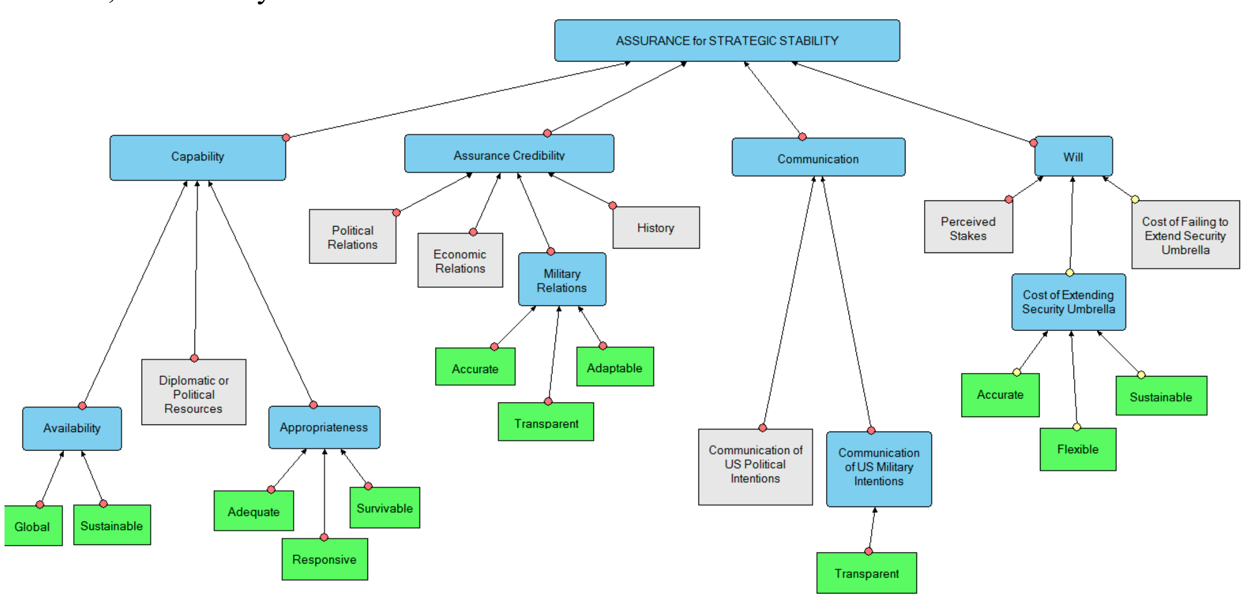

Figure 6. ATOM Structure Authoring Tool — Assurance for Strategic Stability

Capability

See capability discussion on page 9 under direct deterrence.

Communication

See communication discussion on page 10 under direct deterrence.

Assurance Credibility

Political relations: See political relations discussion on page 12 under extended deterrence for strategic stability.

Economic relations: See economic relations discussion on page 13 under extended deterrence for strategic stability.

Military relations: See military relations discussion on page 13 under extended deterrence for strategic stability.

History: See history discussion on page 13 under extended deterrence for strategic stability.

Will

Perceived Stakes: The importance of the issue at stake to the actor is considered a crucial element of credibility. According to rational deterrence theory, in order to be credible the threat must have "demonstrable or reasonable relationship to the maker's real national interests" (Craig & George 1995). The same logic is applicable to instances assurance.

Linkage to force posture: none

Cost of extending security umbrella: The extension of US nuclear security to allies involves both direct and indirect costs. Direct costs are the costs in terms of military manpower and other resources required to project US assurance power. The indirect costs are the negative political and economic ramifications resulting from the placement of US forces and nuclear weapons on foreign territory.

Linkage to force posture: Indirect: accurate, flexible, sustainable

The more sustainable a force posture, the lower the cost of extending protection. Flexible force postures provide options and react to changing conditions, increasing the probability resources exist to provide protection without further investment. More accurate force postures decrease the probability of retargeting requirements, thus decreasing cost

Cost of failing to extend security umbrella: If the US does not use its military capability to assure and protect an ally, it may face economic, reputational and security losses if that ally is later attacked.

Linkage to force posture: none

Assurance for Counter Proliferation

As originally understood, a policy of assurance rests primarily with US promises to extend its "security umbrella" over allied states (often in the hopes of reducing others' incentives to acquire or increase their own nuclear weapons). In considering the role of assurance policy in the future, a 2007 report by the State Department's International Security Advisor Board stated "There is clear evidence in diplomatic channels that US assurance to include the nuclear umbrella have been and continue to be the single most important reason many allies have forsworn nuclear weapons. …a lessening of the US nuclear umbrella could very well trigger a cascade of nuclear proliferation in East Asia and the Middle East (cited in Payne, 2009).

Capability

See capability discussion on page 9 under direct deterrence.

Assurance Credibility

See assurance credibility discussion on page 16 under assurance for strategic stability.

Communication

See communication discussion on page 10 under direct deterrence.

Will

See will discussion on page 16 under assurance for strategic stability.

Assuree Ambitions

See deterree ambitions discussion on page 14 under extended deterrence for counter proliferation.

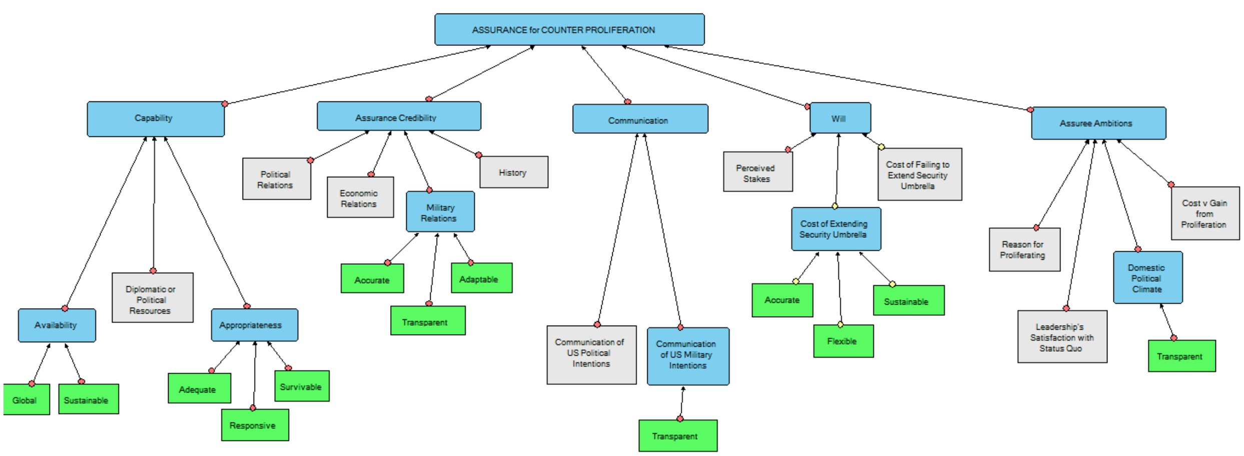

Figure 7. ATOM Structure Authoring Tool — Assurance for Counter Proliferation

Defeat to destroy

For the purposes of the ATOM model, defeat to destroy is defined as a policy objective of massive punishment goals. This involves operations that destroy civilian and military targets with the intent to inflict maximal damage and may include considerable collateral damage (Helfstein et al., 2008, Kaplan, 1982; Rosenberg, 1983, 1987; Wells, 1981). According to the DO JOC (2006), an effective deterrence policy can augment the pursuit of a defeat objective.

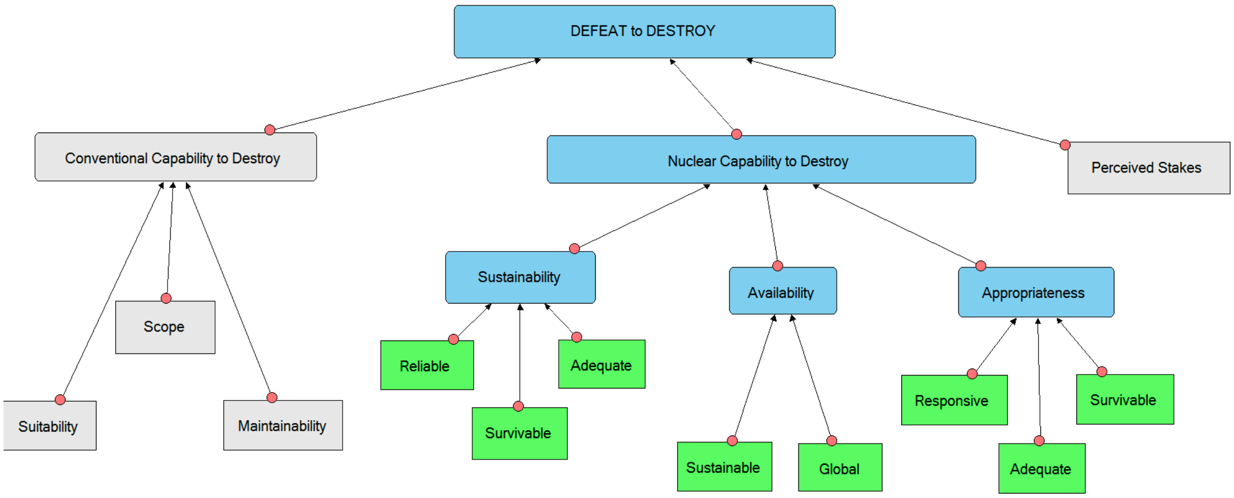

Figure 8. ATOM Structure Authoring Tool — Defeat to Destroy

Conventional capability to destroy

Suitability: Refers to the perceived appropriateness of conventional forces to resolve third-party disputes, and their sufficiency relative to opponent forces.

> *Linkage to force posture:* none

Scope: Refers to the extent of total US security commitments relative to US conventional forces.

> *Linkage to force posture:* none

Maintainability: Captures the ability of the US to maintain a conventional military engagement over time.

> *Linkage to force posture:* none

Nuclear capability to destroy

Sustainability: Refers to the ability of the US to maintain a nuclear engagement over time and with opposition.

> *Linkage to force posture:* Direct: reliable; survivable; adequate
>
> Reliable force postures are more likely to perform, increasing the effectiveness and efficiency of a force posture. Survivable force postures can maintain operability under adverse conditions, and adequate force postures provide sufficient weapons to meet needs.

Availability: Refers to whether US nuclear forces are available, or committed to other US security interests.

Linkage to force posture: Direct: sustainable; global

The coverage generated by global force postures can protect an ally against threats from any geographic location. Sustainable force postures increase affordability and availability.

Appropriateness: Refers to the perceived appropriateness of nuclear forces to resolve third-party disputes and their sufficiency relative to opponent forces.

Linkage to force posture: Direct adequate; responsive; survivable

Responsive force postures allow for rapid changes in alert status or location. Adequate force postures provide target coverage and weapons sufficiency. Survivable force postures increase the probability that US weapons will penetrate enemy defenses

Perceived Stakes

The importance of the issue at stake to the actor is considered a crucial element of credibility. The contention that positive utility is a necessary requirement for conflict initiation has also been demonstrated in the rationalist explanations of war (Bueno de Mesquita 1981), and supports the contention that for a threat to be credible the issuer must have a positive utility for acting on that threat.

Linkage to force posture: none

Defeat to neutralize

For the purposes of the ATOM model, defeat to neutralize is defined as a policy objective of limited punishment goals. This involves limited destruction in two specific scenarios: (a) tactical strikes against an adversary's military assets with the direct purpose of depriving the adversary of those assets, and (b) focused strike against civilian and military targets to dissuade the adversary from escalating conflict (Hagen & Bernstein, 1963; Kaplan, 1982). According to the DO JOC (2006), an effective deterrence policy can augment the pursuit of a defeat objective.

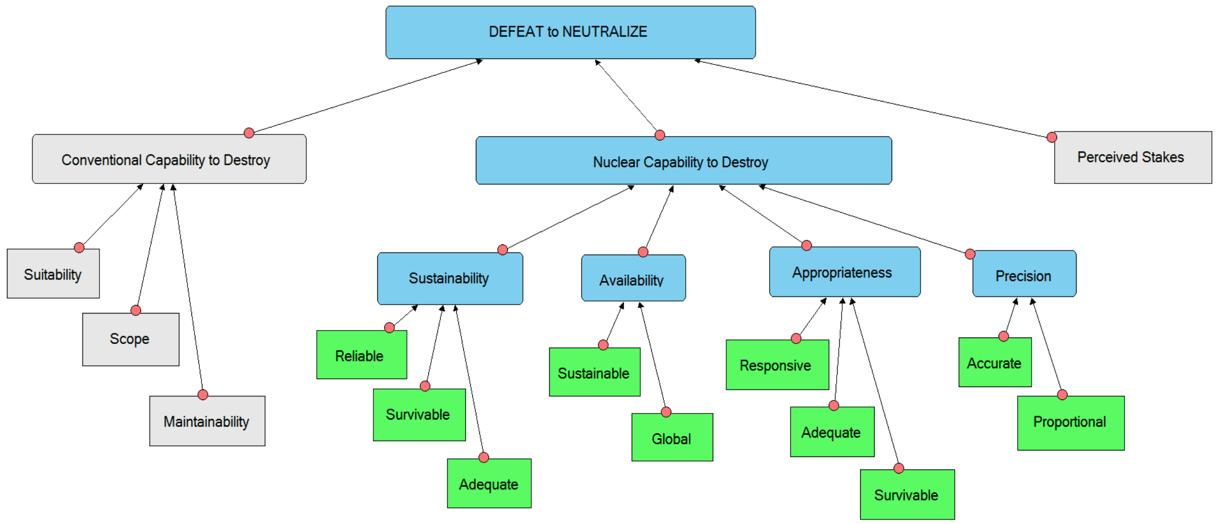

Figure 9. ATOM Structure Authoring Tool — Defeat to Neutralize

Conventional capability to neutralize

See conventional capability discussion on page 18 under defeat to destroy.

Nuclear capability to neutralize

Sustainability: See sustainability discussion on page 18 under defeat to destroy.

Availability: See availability discussion on page 19 under defeat to destroy.

Appropriateness: See appropriateness discussion on page 19 under defeat to destroy.

Precision: Refers to the ability of US nuclear weapons systems to hit specific target and limit collateral damage.

Linkage to force posture: Direct: proportional; accurate

The more proportional and accurate a force posture can be, the greater the precision of the threat it represents and the lower the costs (in terms of collateral damage and political backlash) it can be expected to generate.

Perceived Stakes

See perceived stakes discussion on page 19 under defeat to destroy.

Cost

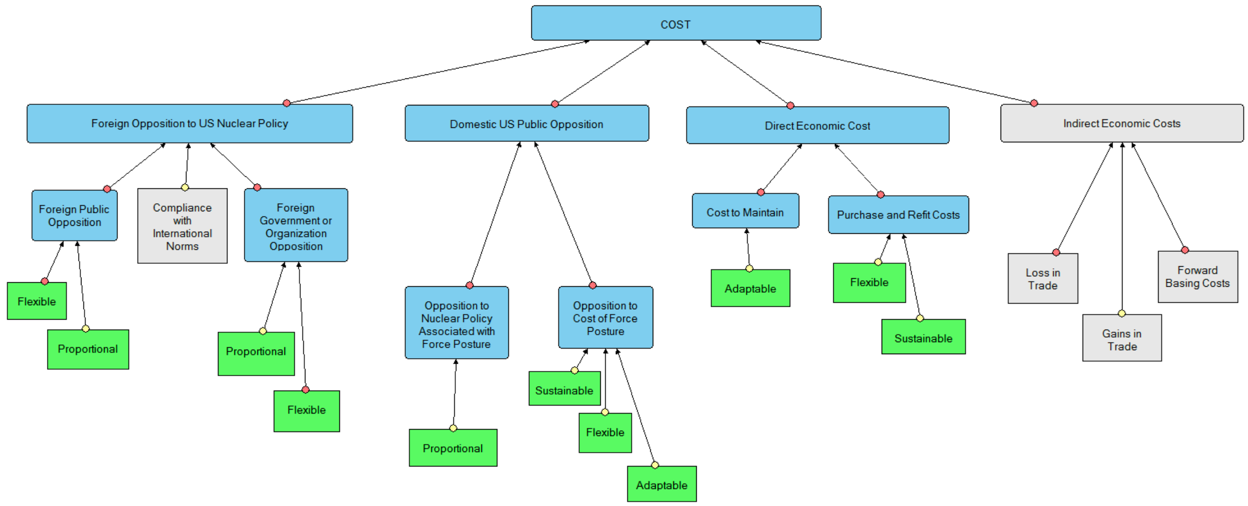

Figure 10. ATOM Structure Authoring Tool — Cost

Foreign opposition to US nuclear policy

Foreign public opposition: Foreign public opposition to US nuclear policy can indirectly increase the cost of that policy to the US. Foreign governments whose populations are resistant to US policy are more constrained in their ability to accommodate US security concerns and more likely to require political concessions before cooperating. Pursuit of these goals in the face of opposition could create further security concerns.

> *Linkage to force posture:* Indirect: proportional; Direct: flexible
>
> Proportional responses decrease the political opposition to use of nuclear weapons. Flexible force postures increase uncertainty regarding how US forces will be deployed and therefore the perceived threat those forces pose to other states.

Compliance with international norms: International norms governing the use of nuclear weapons limit how states can deploy or credibly threaten to deploy nuclear forces. While international norms are not directly enforceable, they do increase the reputational costs of certain actions and leave violators open to sanctions and other punitive actions.

> *Linkage to force posture:* none

Foreign government / organization opposition: If US policy objectives require the cooperation of foreign governments then opposition to these aims can increase the associated political costs or require some form of political accommodation to secure. Alternately, if influential opposition groups or social organizations oppose US nuclear policy they can increase the cost to their government of complying with US needs.

> *Linkage to force posture:* Indirect: proportional; Direct: flexible

Proportional responses decrease political opposition to use of nuclear weapons. Flexible force postures increase uncertainty regarding how US forces will be deployed and therefore the perceived threat those forces pose to other states.

Domestic (US) public opposition

Opposition to nuclear policy associated with force posture: US political leaders must retain popular support in order to retain office. While foreign policy is rarely a deciding factor in Americans' choice of candidates, high salience and high affect issues can generate significant public interest and influence election outcomes.

Linkage to force posture: Direct: proportional

Proportional responses decrease the political opposition to use of nuclear weapons.

Opposition to cost of force posture: While foreign policy issues are rarely decisive in US elections, economic considerations dominate the choices of many voters. When economic conditions are poor, public sensitivity to government spending increases and high cost items are more likely to be resisted. In the post-Cold War era, the relevance of nuclear weapons has increasingly been questioned, making their funding more open to criticism and public attention.

Linkage to force posture: Indirect: sustainable; flexible; adaptable

Adaptable sustainable and flexible force postures are less costly to maintain and therefore generate lower levels of public opposition.

Direct economic cost

Cost to maintain: Refers to the cost to the US of maintaining nuclear weapons and platforms as well as training and equipping the personnel required for their upkeep and deployment.

Linkage to force posture: adaptable

More adaptable force postures provide options and react to changing conditions, increasing the probability resources will exist to provide protection without further investment.

Purchase and refit costs: Refers to the cost to the US of either purchasing nuclear weapons and platforms, or the cost to refit out of date systems.

Linkage to force posture: Indirect: sustainable; flexible

The more sustainable a force posture, the lower the cost of maintenance. Flexible force posture provide options and react to changing conditions, increasing the probability resources exist to provide protection without further investment.

Indirect economic cost

Loss in trade: Loss in trade can result from pursuit of a nuclear policy that is considered by the international community to be in contravention of international norms. Individual trading partners can also use trade restrictions or sanctions as a way to pressure the US into changing a US nuclear policy they disagree with or find threatening.

Linkage to force posture: none

Gains in trade: Just as nuclear policy can be a source of tension between the US and its trading partners, it can also be a means of signaling commitment and thus strengthening economic ties.

Linkage to force posture: none

Forward basing: Securing forward basing locations for US nuclear forces can require the US to agree to additional investment in the locating state.

Linkage to force posture: none

Risk

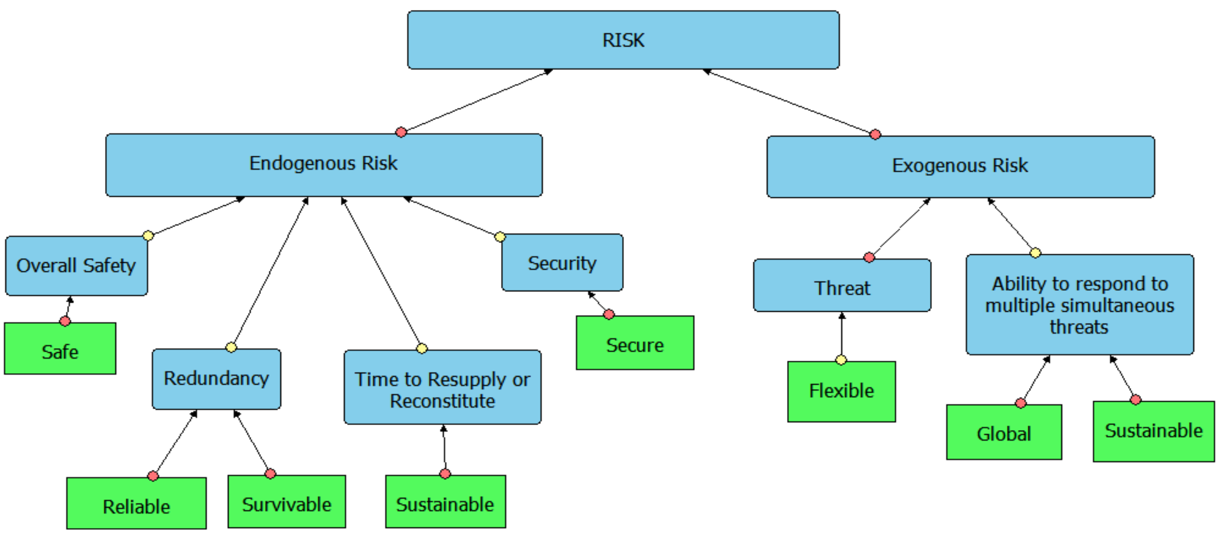

Figure 11. ATOM Structuring Authoring Tool — Risk

Endogenous Risk

Endogenous risk refers to the characteristics of nuclear forces themselves that generate risk.

Overall safety: The safety of US nuclear weapons includes the physical risk to personnel and the general population arising from either accidental exposure or detonation.

Linkage to force posture: Direct: safe

Redundancy: The more redundancy built in to US nuclear capabilities, the less risk is incurred. Accuracy of weapons systems and the reliability of command and control systems help generate redundancy.

> *Linkage to force posture:* Direct: reliable; survivable
>
> Reliable force postures function as intended and have ability to perform required missions. Survivable force postures retain operational integrity even after a (possibly extended and nuclear) attack by an adversary.

Time to resupply or reconstitute: The less time it takes to resupply or reconstitute US nuclear forces after deployment the less risk to which the US is exposed.

> *Linkage to force posture:* Indirect: sustainable
>
> Sustainable force postures can provide nuclear forces and capabilities in accordance with warfighter requirements

Security: Refers to both the likelihood of theft or loss of control of weapons (both on US and foreign territory) as a function of the necessities of storage and deployment and the likelihood of unauthorized or accidental use.

> *Linkage to force posture:* Direct: secure

Exogenous Risk

Exogenous risk refers to contextual factors that can increase the risks associated with nuclear policy objectives.

Threat: Specific nuclear policy objectives are carried out within a larger security environment. The nature of the threats and opponents facing the US change over time and not all can be effectively countered by nuclear forces.

> *Linkage to force posture:* reliable; flexible
>
> Flexible and reliable force postures provide options and enable reaction to changing conditions, increasing the probability resources exist to provide protection against imminent threat.

Ability to respond to multiple simultaneous threats: When the US has the conventional or nuclear force levels to respond to multiple challenges simultaneously, the level of exogenous risk it faces is lowered.

> *Linkage to force posture:* Indirect: global; sustainable

Global force postures enable the US to conduct worldwide operations. Sustainable force postures have the ability to provide nuclear forces and capabilities in accordance with warfighter requirements.

Table 1. Force posture meta-attribute decompositions and component attribute definitions

Meta-attribute	Component attribute(s)	Attribute definitions
Accurate	Accuracy	Measure of average distance from intended target a weapon can achieve, usually expressed as Circular Error Probable (CEP).
	Probability of arrival	Probability of a weapon arriving on desired target.
Adaptable *Provides or enables new capabilities*	Adaptively plan	Ability to adaptively plan (NC2).
	Modular	Includes or uses components which can be interchangeable as units without disassembly of the complete system.
	Open Architecture	The implementation of hardware and software architectures with common specifications that allows for adding, upgrading, and/or swapping components without any proprietary constraints.
	Interoperable	The ability of components, systems, units, or forces to provide services to and accept services from other components, systems, units, or forces and to use the services exchanged to enable them to operate effectively together.
Adequate	Weapon availability given targeting requirement	Achievement of targeting allocation goals.
	Time sensitive and survivable coverage	Ability to meet coverage requirements, whether prompt, survivable, or both.
	Weapon sufficiency	Enough weapons available to cover targets.
	Coverage	Measure of ability to cover sets of targets, target types, target categories, or target numbers.
	Upload capacity	Ability to accommodate the upload of additional warheads. Capacity to which force can be uploaded given available hooks.
	Number of warheads	Warhead count.
Flexible *Can provide options and react to changing conditions*	Basing flexibility	Ability to forward base or change basing modes.
	Force posture options	Ability to change force posture.
	Non-overflight options available	Ability to avoid overflight concerns.
	Yield options	Ability to vary yield to meet a variety of mission requirements.
	Yield selection	Ability to change yield selection prior to execution to adjust to changing conditions.
	Strike flexibility	Ability to adapt the path of strike to avoid overflight or other strike path concerns.
	Delivery platform diversity (offensive forces)	Availability of multiple delivery platforms (across force) to provide effects.

Meta-attribute	Component attribute(s)	Attribute definitions
	Delivery platform diversity (risk mitigation)	Availability of multiple delivery platforms (across force) to provide effects.
	Delivery system diversity (offensive forces)	Availability of multiple delivery systems (per each nuclear leg) to provide effects.
	Delivery system diversity (risk mitigation)	Availability of multiple delivery systems (per each nuclear leg) to provide effects.
	Warhead diversity (offensive forces)	Availability of multiple warheads (per delivery system) to provide effects.
	Warhead diversity (risk mitigation)	Availability of multiple warheads (per delivery system) to provide effects.
	Forward operations options available	Ability to avoid concerns posed via forward operations.
	Prompt delivery options	Ability of multiple delivery platforms/delivery systems to provide prompt effects.
	Ease of retargeting	(Incl. connectivity) "… Associated with assuring stability during the cold war (i.e., reducing the incentive to conduct a first or preemptive strike."
	Recallability	Ability to recall strike during strike operations (post strike initiation).
Global *Can conduct worldwide operations*	Range	Striking distance.
	Range	Ability to reach or engage targets globally.
	Forward basing	During Cold War referred to all US nuclear-capable systems, based in Europe, with the potential to reach targets in the USSR. Now used more generally to refer to US nuclear capabilities located on non-US territory.
Proportional	Proportionality	Ability to deliver effects commensurate with those eliciting the response, particularly including aspects such as yield (low), special effects, target category, and collateral damage.
Reliable *Performs with confidence*	Reliability	Ability to perform nuclear missions with confidence under normal conditions.
	Weapons system reliability (WSR)	Probability of the Weapons System functioning as intended.
Responsive *Can operate within specified time constraints*	Time from execution order to delivery on target	Time it takes to launch a missile from receipt of an execution to key turn to missile lift off to effects on target.
	Time sensitive coverage	Ability to meet time sensitive coverage requirements.
	Time to augment	Time it takes to upload forces to maximum capability.
	Time to generate forces	Time it takes to change force posture from non-alert to alert status.
	Responsiveness	Ability to rapidly change alert status, operational location, or target. Weapons on alert / generation time.

Meta-attribute	Component attribute(s)	Attribute definitions
	Promptness in retaliation	"'Prompt retaliatory launch' capability where forces are on alert and can be launched quickly even during an attack. Owing to the ICBM's high alert rate and continuous secure communications links, it has been that leg of the Triad that has promised the most immediate response."
	Promptness	Ability to rapidly deliver a weapon from its normal status to target.
Safe	Safety	Measure of likelihood and consequences of exposure, error, or accident.
Minimizes likelihood and consequences of exposure, error or accident	Warhead safeguards	No accidental or unauthorized detonations of nuclear weapons due to warhead.
	Delivery system safeguards	No accidental or unauthorized detonations of nuclear weapons due to delivery system.
Secure	Security	Measure of likelihood and consequences of unauthorized access.
Prevents likelihood and consequences of unauthorized action	Warhead positive control	Positive inventory control of nuclear stockpile.
	Delivery platform positive control	Positive inventory control of nuclear stockpile.
Survivable	Survivability	Ability to maintain acceptable operational capability (to respond) under adverse conditions, particularly adversary attack. • Alternatively: "Associated with assuring stability during the cold war (i.e., reducing the incentive to conduct a first or preemptive strike). This also include the ease of or ability to disperse assets (e.g., SLBMS at sea or in port; bombers dispersed across land or in the air)." • This attribute applies primarily at the asset level, but should also be aggregated at the "leg" and "force" level. Possible contributors to survivability include: presenting many, disparate targets; asset and platform mobility; hardened sites or postures; deception techniques; etc.
Maintains operational capability under adverse conditions	Endurability	Ability to retain operational integrity even after a (possibly extended and nuclear) attack by an adversary.
	Nuclear hardened	Like the B2, which can fly low through areas where nukes have already gone off.
	Survivable coverage	Ability to meet survivable coverage requirements.
	Survivable delivery options	Ability of multiple delivery platforms / delivery systems to survive a nuclear perturbed environment.
	Pre-launch survivability (PLS)	The probability that a delivery or launch vehicle will survive an enemy attack under an established condition of warning.
	Targetability	Relative ease for adversary to target US assets. (This is a form of vulnerability.)

Meta-attribute	Component attribute(s)	Attribute definitions
	Penetrability	Ability to survive enemy defenses to the point of weapon effects delivery. • Alternatively: "The ability to penetrate defenses, hardened targets. Related to probability of destruction and includes ability to penetrate air defenses, etc."
	Probability to penetrate (PTP)	The probability that a delivery platform or delivery system will survive enemy defenses in order to deliver effects.
	Overkill	Ability to achieve desired effect with minimal force.
	Targets/aimpoints	Posing difficulties for an adversary trying to defend itself from a second strike.
	Correlation of forces	Degree of deviation between U.S. and adversary forces.
Sustainable *Affordable, maintainable, feasible and available*	Affordability	Cost of maintaining and sustaining the nuclear forces. Cost [in $] to acquire, maintain, sustain, and operate forces.
	Feasibility	Service ability to organize, train, & equip nuclear forces.
	Availability	Service ability to provide nuclear forces and capabilities in accordance with warfighter requirements. Fraction of force in a state of readiness for immediate use.
	Maintainability	Service ability to provide viable nuclear forces and capabilities.
	Connectivity with C2 systems	"… and the degree to which this could be maintained in the event of an attack."
	Azimuth options available	Ability to bypass clipping concerns.
	Fuzing [sic] options	Ability to change fuzing to alter weapon effects.
Transparent	Transparency	Openness of forces or plans to view or inspection by allies or potential adversaries.
	Visibility	Ability to display a change in alert posture, escalatory intent, or mere capability.
	Visibility / transparency	Ability to display a change in force posture.
	Signaling	Attribute associated with bombers. Ability to signal readiness changes through stages of a crisis; associated with assuring stability during the cold war (i.e., reducing the incentive to conduct a first or preemptive strike).

ATOM Software Overview

The ATOM software is comprised of a Structure Authoring Tool to assist users in decomposing complex problems into a hierarchical structure, terminating in basic attributes that can be directly assessed, and a decision support engine that aggregates the evaluation of higher-order concepts in the decomposition on the basis of their contributing elements.

ATOM Structure Authoring Tool

The ATOM Structure Authoring Tool allows users to configure and visualize the relationships between policy objectives and force posture meta-attributes that comprise the problem space. The Structure Authoring Tool exports a structure file for use in the ATOM Decision Support Engine (DSE).

Functionality

- ATOM visualization can be used independently as a tool for mapping a particular problem space, or the structure can be exported into the DSE for further analysis.
- Users can manipulate and change: elements (policy objectives and dimensions, force posture meta-attributes); relationships between elements; and the direction and weights of these relationships.
- Important unmeasured elements can be included in visualization yet excluded from computational analysis (gray nodes in Figure 12).

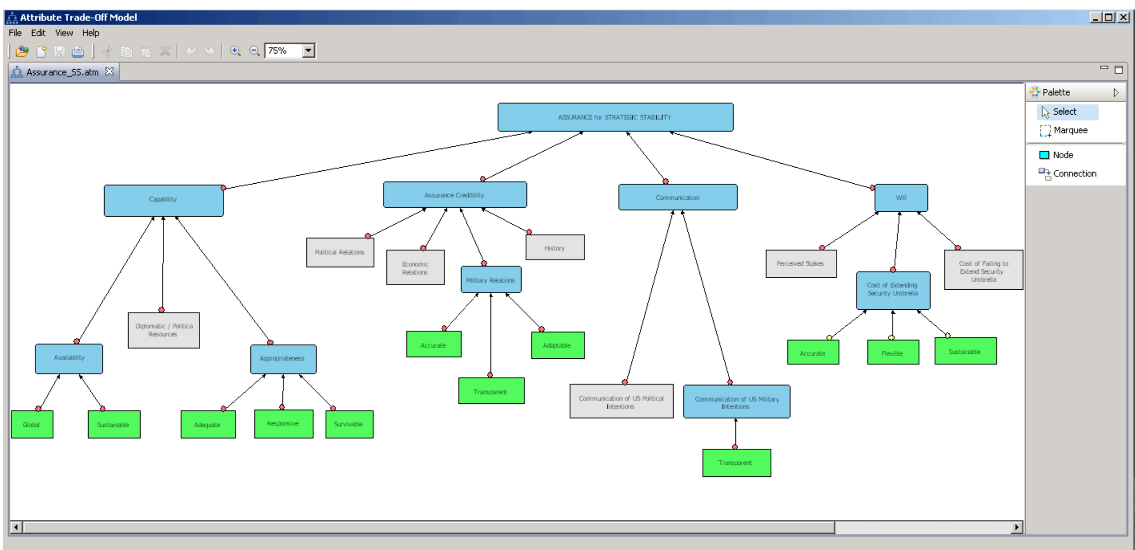

Figure 12. Screen shot of the ATOM Structure Authoring Tool

ATOM Decision Support Engine

The DSE reads in a problem structure and assessment values for the force posture meta-attributes, which collectively constitute a **force posture** for the purposes of the ATOM analysis. It then aggregates the assessments up the structure using either the Simple Additive Weighting (SAW, see Yoon & Hwang 1995: 32-36) or Evidential Reasoning (ER, see Yang & Xu 2002) method. The DSE allows users to compare as many alternative force postures as desired. It also permits users to specify as many alternative combinations of high-level policy objectives (the top-level branches of the problem space hierarchy) as desired to obtain an overall assessment. For example, users may wish to examine an overall assessment considering only Assurance for Strategic Stability and Cost, or they may wish an overall assessment considering all forms of Deterrence and Risk.

Aggregation algorithms

SAW: Aggregates by assessing a parent as the weighted average assessment of its descendants.

- Weights are the edge weights supplied in the structural decomposition of the problem space and specified in the ATOM Structure Authoring Tool.
- Assessments at the most basic level of the decomposition are on force posture meta-attributes and each meta-attribute must be given a single value within the discrete evaluation scale.
- Parent nodes may not be evaluated to a value on the discrete evaluation scale, but may be assessed to intermediate values (see Figure 13).

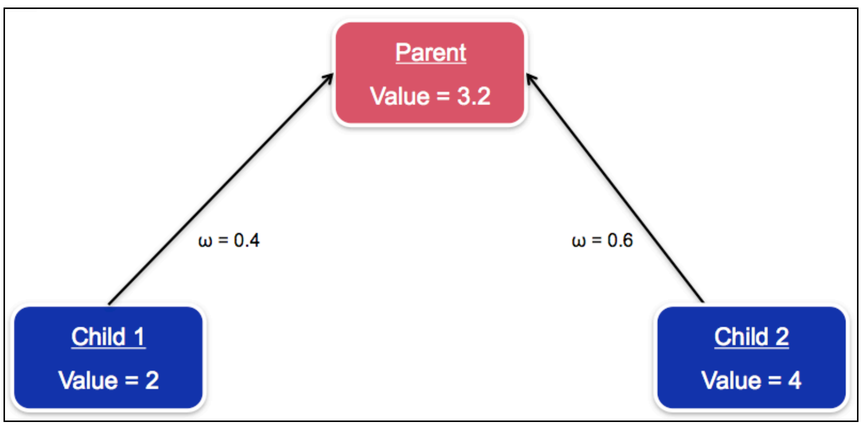

Figure 13. Example aggregation using SAW

ER: Employs a more complex scheme whereby assessments of elements may be distributed across the evaluation scale rather than concentrated on one value.

- For example, rather than assessing an element as a 2 out of 5, one could assess it as a 2 with 75% *belief* and a 3 with 25% belief (see Figure 14).
- Parent nodes in the decomposition are assessed on the same scale as their descendants, with the distribution of belief determined by belief distributions on the child nodes and the edge weightings joining them to the parent.

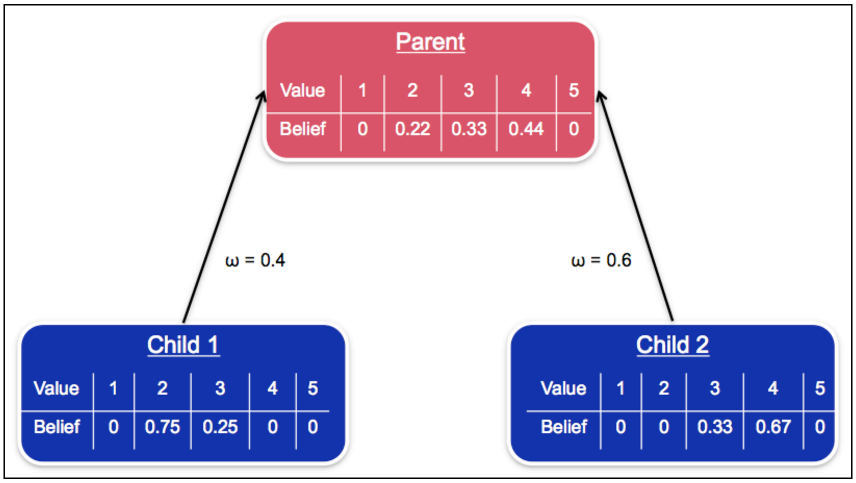

Figure 14. Example aggregation using ER

Comparison of aggregation methodologies

Simple Additive Weighting

- Simple to use and explain
- Requires evaluating the most basic elements to an exact value on the assessment scale
- Assumes that the assessment scale is interval-valued; that is, the true value between any two points on the assessment scale is assumed to be the same
- Calculated nodes will usually not be expressed on the same scale as the basic nodes; that is, they will be fractional whereas the basic scale may be integer-valued
- Can lend a false sense of precision to the decision analysis process

Evidential Reasoning

- Not as simple to use or explain
- Allows for uncertainty in the assessment of basic elements, including the type of varied input that might be obtained by surveying a panel of experts
- Results of the assessment aggregation may require additional assumptions regarding the utility of each value on the evaluation scale to conclude a definitive ranking of choice alternatives
- Well suited to identifying alternatives with extreme risk/reward potential

ATOM User's Guide

Using the ATOM Structure Authoring Tool

The ATOM Structure Authoring Tool is a Java-based program that runs under Windows. Its look and feel is similar to all Windows programs, with menus that will be familiar to all users.

Installation

The software is delivered in a containing folder enclosed in a ZIP archive and is installed by unzipping the archive to any convenient location. The containing folder may be placed in the Program Files directory, though this is not required. All the necessary libraries required to run the program are included in the folder. To run the tool, simply run the ATOM.exe executable contained within the folder. A shortcut to this executable file can be placed on the desktop, quick launch bar, or any other desirable location.

The application requires version 1.6 of the Java Runtime Environment (JRE), which has been standard on personal computers for several years.

Included in this archived folder is a subfolder called ATOM structure files. This contains the structure specified in the ATOM theoretical model discussed above.

Creating and editing problem structures

The File menu functions can be used to open an existing structure file or to create a new one. ATOM structure files have a .atm extension, and the ATOM Structure Authoring Tool open dialog will look for these files by default. Alternatively, the shortcuts under the menu can be used for standard file functions (Open, New, Save, Print—see Figure 15). Several structure files can be open simultaneously and will be loaded into separate tabs for convenient navigation (see Figure 18).

ATOM structures consist of nodes and edges. When a file is active, the user can add nodes and edges by opening the Palette on the right edge of the window and using the appropriate tools (see Figure 16). New nodes will be added with a default name (the internal node ID that is assigned by ATOM to each node upon creation). This can be changed in the node properties dialog box, which will be described below.

To delete an element (node or edge), select it and then Delete from the Edit menu. Alternatively, the delete symbol may be selected from the edit tools from the shortcuts (see Figure 17), or the Delete key on the keyboard can be used.

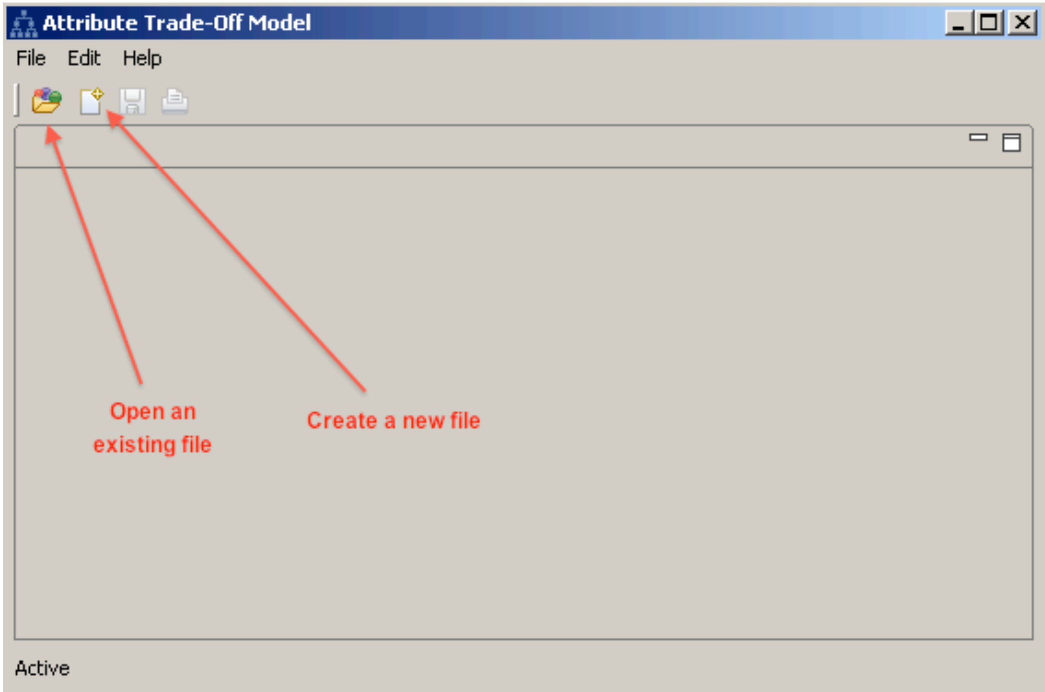

Figure 15. Shortcuts for ATOM Structure Authoring Tool file operations

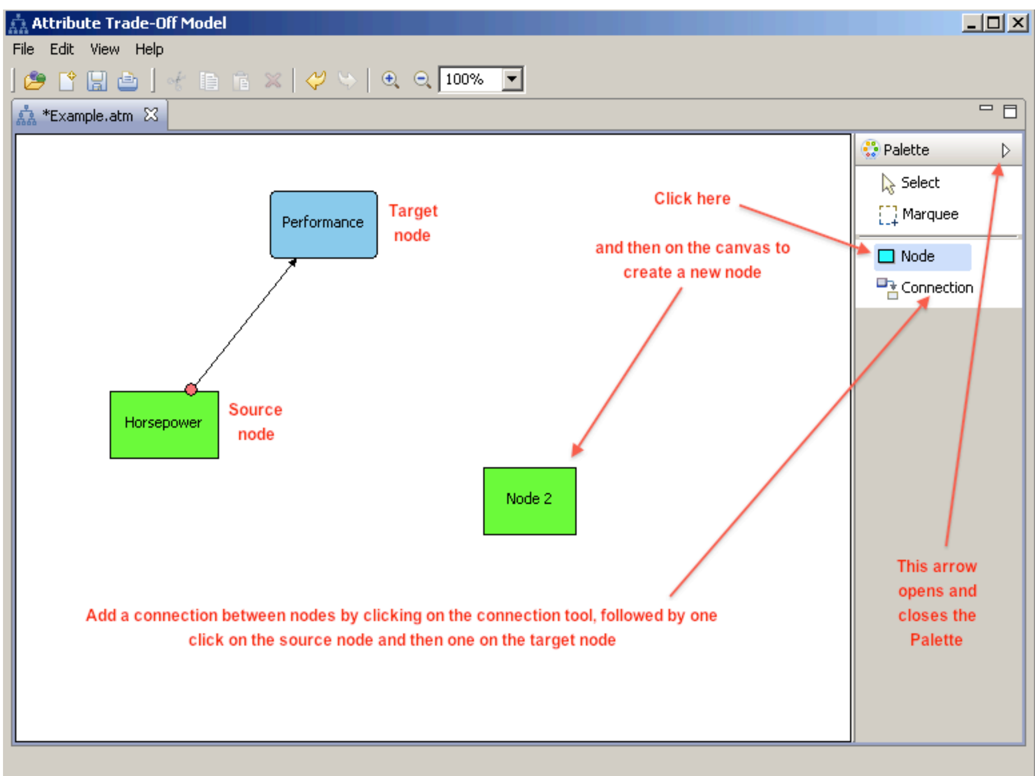

Figure 16. Node and edge creation tools

Editing node and edge properties

Once nodes and edges are placed in the diagram, their properties can be edited using the respective property dialog boxes. To access either of these, double click on the desired element and the dialog will open.

The node dialog allows the user to enter a label for the node along with notes. A checkbox is also present to indicate whether the node is unmeasured. Unmeasured nodes are not used in the subsequent aggregation analysis performed by the DSE, but are allowed to provide the user a way of visualizing exogenous or contextual elements that are not to be formally assessed. See Figure 18 for an example of a node properties dialog.

Care should be taken when labeling nodes since the DSE will assume that nodes with the same label are the same element in the problem structure. **This is true for elements in the same structure file as well as elements in separate structure files that are used to diagram the same problem space.** The ability to use several files to specify a problem space is a convenience only; once these several files are ingested into the DSE, the structure is unified as if it were authored in one file. **Node labels should only include letters, spaces, numerals and the underscore character; no other symbol should be used.**

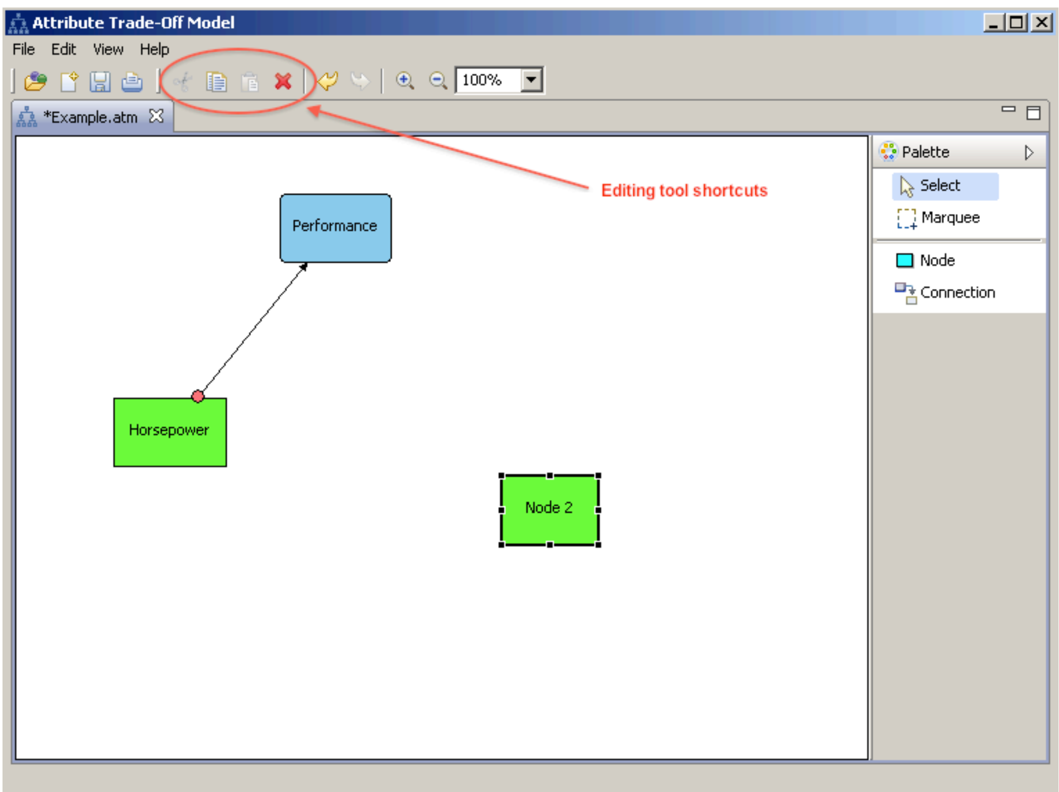

Figure 17. ATOM editing shortcuts

Note that there is no control over node coloring in the properties dialog. This is because ATOM assigns node colors automatically based upon their functional role in the problem decomposition.

Unmeasured nodes are colored gray, nodes that have no child nodes (sometimes referred to as leaves) are colored green, and nodes that will be assessed on the basis of their child nodes are colored blue. ATOM assumes that assessment values for the leaves will be provided as an input to the DSE in a separate file not generated by the Structure Authoring Tool. See the discussion below on the DSE for more detail.

The edge properties dialog allows for the setting of edge weight and orientation. By default all edges are set to a weight of 1.0 and a direct orientation (that is, implying that the parent node varies directly with the child node). The edge weight can be any nonnegative value. Since the DSE will normalize the weights among all the child nodes of a common parent so that they sum to 1, care should be given to the *relative* weightings assigned to child nodes of the same parent. For example, all else being equal, DSE computations with weightings of 0.33 and 0.67 will be identical to those with weightings of 1 and 2.

Users may specify an indirect edge orientation by setting the check box (see Figure 19). As with the node coloring, the color of the indicator circle attached to each edge is set automatically. A red circle indicates a direct relationship and a yellow one an indirect relationship.

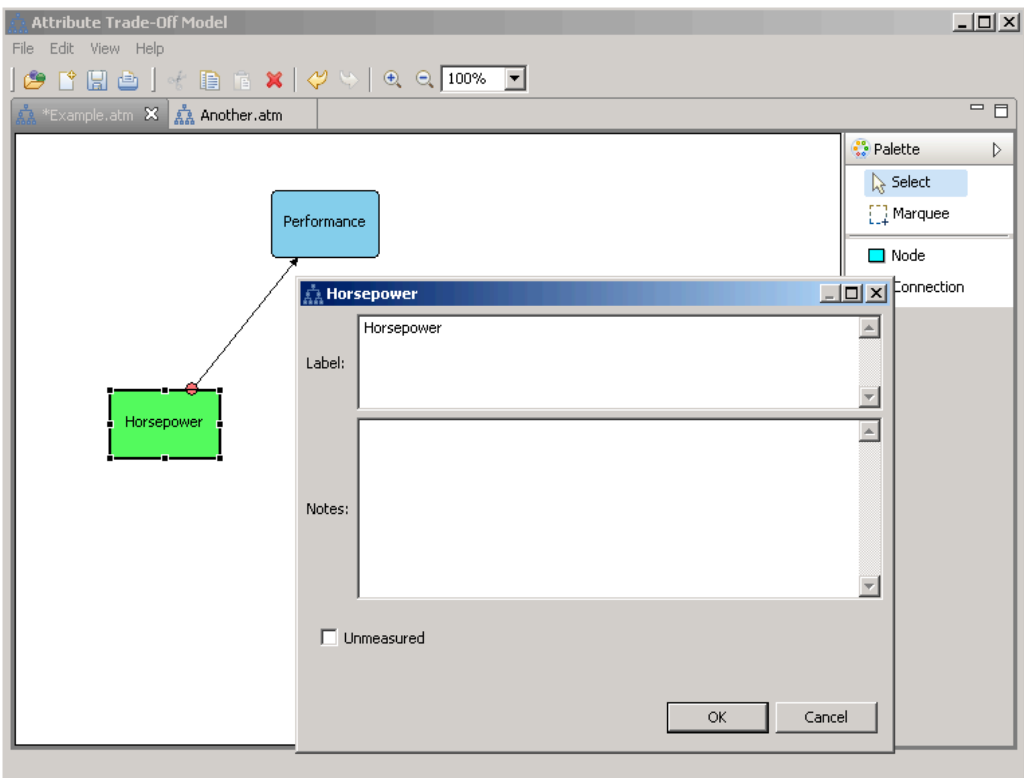

Figure 18. ATOM node properties dialog

Exporting the ATOM structure for use in the DSE

Exporting the structure created in the ATOM Structuring Tool for use in the DSE is straightforward. Once all elements, both nodes and edges, have been created and their properties set, save the structure file and then from the File menu choose Export Structure. A dialog box will appear with a default file name equal to the current structure file name pre-populated for convenience. The user can override this and change the name of the export file, if desired. The Structure Authoring Tool will write out a comma-separated file (CSV) suitable for import into the DSE. The Structure Authoring Tool also allows for export of a purely visual rendition of the structure in JPEG format. This functionality is also available on the File menu by choosing Export Image.

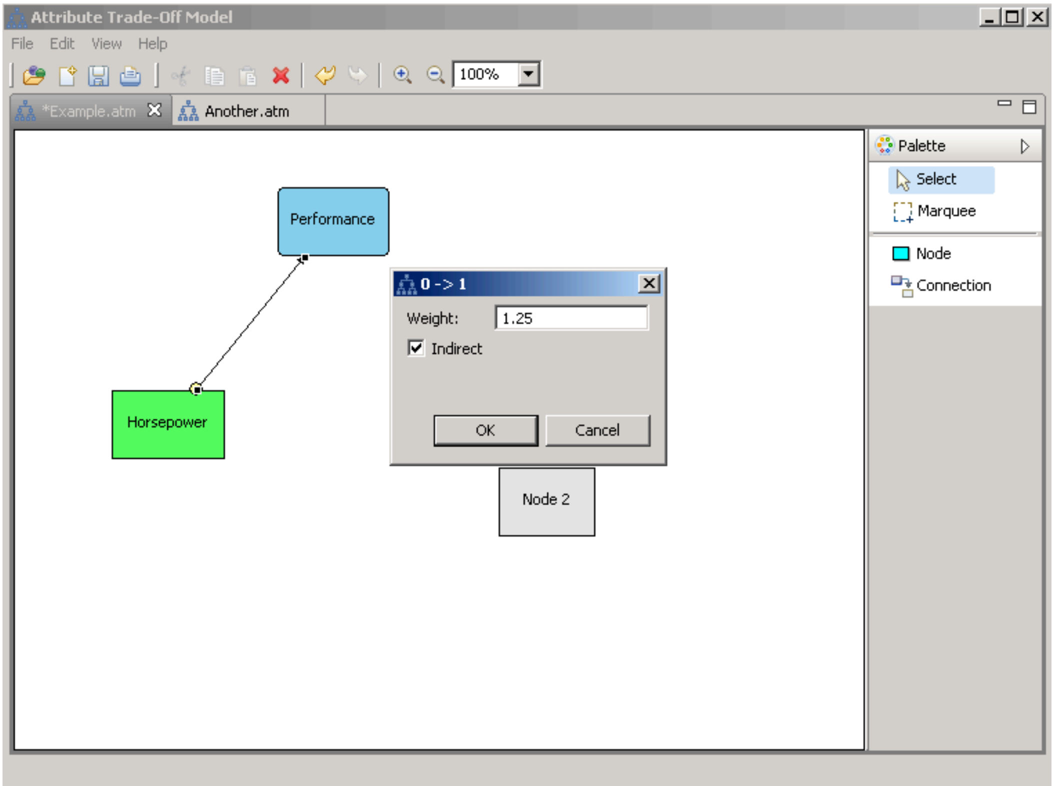

Figure 19. ATOM edge properties dialog

Running the ATOM DSE

Quick Start

The ATOM Decision Support Engine is written in the scripting language of R, an open source statistical analysis application that is available for Windows, Mac OS X, and UNIX operating systems (including Linux). The ATOM DSE scripts have been tested in Windows and Mac OS X environments, and it is expected that they should run without issue on other platforms supported by R.

The current version of the ATOM DSE is delivered as a set of files and folders, all of which should be placed in the same folder on the host computer. A list of the files and folders included in the ATOM DSE package that was prepared for the CANS Policy Objective analysis is shown in Table 2.

Table 2. ATOM DSE files and folders

```
SCRIPTS
    ./ATOM.R
    ./ATOM_part2.R
    ./ATOM_WEB_OUTPUT.R
CONFIGURATION AND DATA FILES
    ./ATOM_config.txt
    ./ATOM_leaf_vals.csv
    ./ATOM_branch_weights.csv
FOLDERS
    ./branches/
    ./html_rsrcs/
    ./output?
```

To run an analysis, first launch the R GUI application on the host computer. The optimal set up for running the ATOM DSE is to configure the R environment so that its working directory is the directory that contains the ATOM DSE files listed above. In Windows, select the *Change dir…* command from the *File* menu in the R GUI application, and browse to the ATOM folder. Alternatively, use the `setwd()` command in R to define the working directory to be the folder that contains the ATOM.R script. (Type `help(setwd)` at the prompt in the R GUI for more information about the `setwd()` command.) To confirm that the ATOM folder is the working directory, list the contents of the working folder by entering the command `dir()` at the prompt in the R GUI.

Once the working directory has been properly set and the analysis configuration and data are in place, begin the ATOM DSE analysis by entering the following command at the prompt in the R GUI.

```
source("ATOM.R")
```

For a modest analysis (three alternatives and three top-level weight vectors using a five-level assessment scale), the results should be available fairly quickly. When compete, the R script will launch the default browser on the host machine and load the HTML-formatted output.

The following sections describe in greater detail each of the files and folders that together make up the ATOM DSE tool.

Included files

The delivered tool comprises a set of three R scripts, a configuration file, and a collection of files that define the structure of problem to be analyzed and the inputs required for executing the analysis. In addition, there is a small collection of files that are used when dynamically generating HTML output for presenting the results of an analysis. Detailed information about each of these resources is provided in the sections below.

R scripts

The current version of the ATOM Decision Support Engine is divided into three separate R scripts: `ATOM.R`, `ATOM_part2.R`, and `ATOM_WEB_OUTPUT.R`.

`ATOM.R` This script file contains code to combine meta-attribute scores up the problem decomposition trees, producing SAW or ER scores for cost, risk, and the seven policy objectives as well as all the intermediate elements and dimensions that connect those objectives to the meta-attributes. If the input to the analysis is a set of related problem decomposition trees, as in the CANS ATOM analysis, the script creates an "Overall Evaluation" node that combines the top-level nodes of those trees into a single score based on a weight vector that is provided as input (described below). The output of this script contains the primary results of the analysis, which are written to disk as CSV files that can be opened and viewed in Microsoft Excel or imported to an alternative statistical software application (such as SPSS or Stata) for further analysis. If meta-attribute scores for two or more force postures are provided in the analysis configuration, the output contains a table of node scores for each force posture.

In the current version of the `ATOM.R` script, one of the first commands in the script clears all objects from the R workspace to minimize the likelihood of conflicts as well as the size of the Rdata file that is stored at the end of the analysis. If there are data in the R workspace prior to running an ATOM DSE analysis, those data should be saved before launching the `ATOM.R` script.

NOTE: At the present time, the name of the ATOM DSE configuration file is written into the ATOM.R file. To analyze different configurations within the same working directory, either the filename in the ATOM.R file must be updated to reflect the name of the desired configuration file or alternative file names must be assigned to inactive configuration files in the file system while 'ATOM_config.txt' is reserved for the configuration of the active analysis.

`ATOM_part2.R` This script file is only used when two conditions are met: (1) the input to the analysis is a set of related problem decomposition trees, as in the CANS policy objectives analysis; and (2) two or more weight vectors for combining the trees into an overall evaluation are provided in the analysis configuration. When executed, this script computes a table of Overall Evaluation scores for each force posture (as described above) and each branch weight vector.

`ATOM_WEB_OUTPUT.R` This script file generates a collection of HTML files that are stored locally in the output folder and can be viewed in any modern web browser. The HTML output is intended to provide a means for quickly viewing the assessments that have been computed for all of the nodes in the problem structure. A separate set of data files suitable for use in secondary data analysis is saved at the end of each run.

Configuration file

`ATOM_config.txt` The ATOM DSE configuration file contains information defining the parameters for an analysis. The contents of a sample configuration file are shown in Data files

The simplest application of the ATOM DSE requires two data files: one file to define the structure of the problem to be analyzed and one file to specify the ratings that have been assigned to the lowest-level nodes on the problem hierarchy. For the CANS policy objective analysis, the problem structure has been divided into nine separate files. For this reason, an additional data file is required to specify how the nine branches of the problem are to be integrated for an overall evaluation. The three kinds of data files are described in more detail below. Note that for the purpose of organizing the data, the nine problem structure files defining the CANS policy objective analysis have been placed in a folder called *branches*.

Problem structure

Although the easiest way to produce a structure file for the ATOM DSE is to diagram the problem using the ATOM Structure Authoring Tool and export the problem structure to a CSV file, the problem structure for simple problems can be created using any software that can save to a CSV text file (e.g., Microsoft Excel, SimpleText). The content of a sample problem structure file is shown in Table 4.

Table 3. The configuration file specifies ten pieces of information for the ATOM DSE analysis.

1. TITLE. This parameter specifies a name under which output from the analysis will be stored. Multiple runs with the same configuration title are stored in separate folders that are named according to the date and time at which the run is initiated. The TITLE parameter is stored as a string variable in R and should contain no spaces or quotation marks.
2. NSTRUCTUREFILES. This parameter specifies the number of problem structure files that have been created for the problem being analyzed. In the case of the CANS policy objective analysis, there are nine structure files. The NSTRUCTUREFILES parameter is stored as a numeric variable in R.
3. BRANCHWEIGHTSFILE. This parameter specifies the name of a comma-separated values (CSV) file that contains information about how the structure files should be combined to produce an overall evaluation of the problem. If there is only one structure file used in the analysis (i.e., if NSTRUCTUREFILES = 1), this parameter need not be specified (though the BRANCHWEIGHTSFILE line in the configuration file should not, itself, be deleted). The BRANCHWEIGHTSFILE parameter is stored as a string variable in R. To avoid errors, file names should be limited to the characters A–Z, a–z, 0–9, dash, and underscore, and the filename should end with the extension ".csv".
4. NSCALELEVELS. This parameter specifies the number of levels in the rating scale that is used to score the meta-attributes. For example, if the meta-attributes are scored on an integer scale of 1 to 5, then NSCALELEVELS = 5. The NSCALELEVELS parameter is stored as a numeric variable in R.

5. RATINGSCALELABELS. This parameter specifies the labels that will be used for each level of the rating scale. Labels should be provided in a list on one line of the configuration file with entries separated by commas. Labels should contain no spaces and no quotation marks. To avoid errors, labels should be limited to the characters A–Z, a–z, 0–9, dash, and underscore. The RATINGSCALELABELS parameter is stored as a vector of string variables in R.
6. NALTERNATIVES. This parameter specifies the number of alternatives being compared in the analysis. For each alternative included in the analysis, a separate set of meta-attribute scores must be provided, as discussed below. The NALTERNATIVES parameter is stored as a numeric variable in R.
7. ALTERNATIVESLABELS. This parameter specifies the labels that will be used for each alternative in the analysis. Labels should be provided in a list on one line of the configuration file with entries separated by commas. Labels should contain no spaces and no quotation marks. To avoid errors, labels should be limited to the characters A–Z, a–z, 0–9, dash, and underscore. The ALTERNATIVESLABELS parameter is stored as a vector of string variables in R.
8. ALTERNATIVESRATINGSFILE. This parameter specifies the name of a comma-separated values (CSV) file that contains information about how the meta-attribute nodes have been scored for each force posture alternative in the analysis. This parameter cannot be omitted, even if only one alternative is being examined in a given iteration. The ALTERNATIVESRATINGSFILE parameter is stored as a string variable in R. To avoid errors, file names should be limited to A–Z, a–z, 0–9, dash, and underscore, and the filename should end with the extension ".csv".
9. ANALYSES. This parameter specifies which analytic algorithms are to be applied in the analysis. At present, the only alternatives are "SAW" for the simple additive weighting algorithm and "ER" for the evidential reasoning algorithm. Note that SAW can only be applied if meta-attribute scores are specified as point estimates; that is, only if each meta-attribute for each force posture to be evaluated is assessed to a single value on the evaluation scale. Algorithm labels (SAW, ER) should be provided in a list on one line of the configuration file with entries separated by commas. The ANALYSES parameter is stored as a vector of string variables in R.
10. STRUCTUREFILES. This section of the configuration file contains a list of names for the CSV files that define the problem structure that is being analyzed. Each filename should appear on a separate line of the configuration file, and the number of entries should match the value specified for the parameter NSTRUCTUREFILES. Entries should contain no spaces and no quotation marks. A subdirectory in which the files have been placed can be specified relative to the directory in which the ATOM scripts and the configuration file have been stored. To avoid errors, subdirectory names and file names should be limited to A–Z, a–z, 0–9, dash, and underscore, and the file names should end with the extension ".csv"

Data files

The simplest application of the ATOM DSE requires two data files: one file to define the structure of the problem to be analyzed and one file to specify the ratings that have been assigned to the lowest-level nodes on the problem hierarchy. For the CANS policy objective analysis, the problem structure has been divided into nine separate files. For this reason, an additional data file is required to specify how the nine branches of the problem are to be integrated for an overall evaluation. The three kinds of data files are described in more detail below. Note that for the purpose of organizing the data, the nine problem structure files defining the CANS policy objective analysis have been placed in a folder called *branches*.

Problem structure

Although the easiest way to produce a structure file for the ATOM DSE is to diagram the problem using the ATOM Structure Authoring Tool and export the problem structure to a CSV file, the problem structure for simple problems can be created using any software that can save to a CSV text file (e.g., Microsoft Excel, SimpleText). The content of a sample problem structure file is shown in Table 4.

Table 3. Sample contents of an ATOM DSE configuration file

```
 # The R script extracts information from N structure files and 1 ratings file.
Comments at end of a line should be marked by a semicolon (;)

&PARAMS
TITLE = CANS_test_model ; no spaces, no quotes - R will read the value on this line as
a single string and it will be used to name the output directory

NSTRUCTUREFILES = 9 ; file names are listed at the end of this file
BRANCHWEIGHTSFILE = ATOM_branch_weights.csv ; must exist if using multiple structure
files and must contain at least three columns (branch name, coding, weight),
additional columns specify branch weights for secondary analyses of top-level roll-up

NSCALELEVELS = 5 ; labels for the levels are provided below
RATINGSCALELABELS = R1, R2, R3, R4, R5 ; could be anything, separated by commas with
no quotes

NALTERNATIVES = 3 ; labels for the alternatives are provided below
ALTERNATIVESLABELS = FP_A, FP_B, FP_C ; could be anything, separated by commas with no
quotes
ALTERNATIVESRATINGSFILE = ATOM_leaf_vals.csv ; table must have
[1+(NSCALELEVELS*NALTERNATIVES)] columns

ANALYSES = SAW, ER ; SAW requests Simple Average Weighting, ER requests Evidential
Reasoning
&END

&STRUCTUREFILES
branches/Assurance_CP.csv
branches/Assurance_SS.csv
branches/Cost.csv
branches/Defeat_Destroy.csv
branches/Defeat_Neutralize.csv
branches/Deterrence_Direct.csv
branches/Deterrence_Extended_CP.csv
branches/Deterrence_Extended_SS.csv
branches/Risk.csv
```

Table 4. Sample problem structure file in CSV format

```
2,Direct Deterrence Credibility,0,DIRECT DETERRENCE,d,1
5,Proportionality of Threat,2,Direct Deterrence Credibility,d,1
9,Proportional,5,Proportionality of Threat,d,1
12,Communication of US Military Intentions,18,Communication,d,1
16,Transparent,12,Communication of US Military Intentions,d,1
18,Communication,0,DIRECT DETERRENCE,d,1
29,Global,36,Availability,d,1
30,Capability,0,DIRECT DETERRENCE,d,1
31,Appropriateness,30,Capability,d,1
32,Responsive,31,Appropriateness,d,1
34,Survivable,31,Appropriateness,d,1
35,Adequate,31,Appropriateness,d,1
36,Availability,30,Capability,d,1
38,Sustainable,36,Availability,d,1
```

The problem structure data are organized as *edge lists* in which each row defines a connection from a child node to a parent node. The first two entries in a row specify the child node in terms of a node ID number and a node name, while the second two entries specify the node ID number and node name of the parent node. The fifth entry in a row indicates whether the relationship between child and parent is direct, denoted by a lower case “d” (without quotation marks) or indirect, denoted by a lower case “i." The final entry in a row is a numeric value indicating the weight that has been assigned to that particular child–parent connection. Note that the weight value can only be accurately interpreted when considering all the weights that have been assigned to connections from a set of child nodes to their common parent node.

Both node ID numbers and node names must be uniquely assigned. Moreover, although node ID values are not currently used by the ATOM DSE R scripts, node names must be consistently assigned across all problem structure files that are used for a given analysis. Thus, if a node labeled *Availability* appears in two or more different problem structures within a single analysis, then the same node name must be used in all of those problem structure files. If, however, a user wants to distinguish between an *Availability* node in one structure file and an *Availability* node that appears in another structure file, then the nodes must be given different names in those files. No separate list of all nodes that appear in a given problem space is required. The R script infers a list of all unique node names while pre-processing the input data.

Meta-attribute scores

As noted previously, the principal function of the ATOM DSE is to compute assessments of high-level policy objectives and intermediate elements and dimensions based on assessments of a set of meta-attributes whose scope is easier to apprehend. Currently, the only way to specify meta-attribute scores for the ATOM DSE is with a CSV text file that must be created manually using any software that can save to a CSV text file (e.g., Microsoft Excel, SimpleText). The content of a sample meta-attribute scores file is shown in Table 5.

Table 5. Sample meta-attribute assessment scores in CSV format

```
Accurate,0,0,1,0,0,0,1,0,0,0,0,0,0,0,1
Adaptable,0,0,0,0,1,0,0,1,0,0,1,0,0,0,0
Adequate,1,0,0,0,0,0,0,0,0,1,0,0,0,0,1
Flexible,0,0,0,0,1,0,0,0,1,0,1,0,0,0,0
Global,0,0,0,0,1,0,0,1,0,0,1,0,0,0,0
Proportional,0,0,0,0,1,0,1,0,0,0,0,0,1,0,0
Reliable,0,1,0,0,0,0,0,1,0,0,0,0,0,0,1
Responsive,0,0,0,0,1,0,0,0,1,0,1,0,0,0,0
Safe,0,1,0,0,0,0,1,0,0,0,0,0,1,0,0
Secure,0,0,0,0,1,0,0,0,0,1,1,0,0,0,0
Survivable,1,0,0,0,0,0,0,0,1,0,1,0,0,0,0
Sustainable,0,0,0,0,1,0,0,1,0,0,0,0,0,1,0
Transparent,0,0,0,1,0,1,0,0,0,0,0,1,0,0,0
```

Each row in the meta-attribute scores file corresponds to one meta-attribute that appears in the problem structure. Note that although the R scripts are capable of inferring which nodes in the problem structure are meta-attributes, there is no error checking in the current version of the software to verify that the list of meta-attributes in the assessment scores file matches the meta-attributes implied by the problem structure files. The user must confirm that the list of entries in the meta-attribute score file is complete and correct.

The first entry in each row is the name of the meta-attribute. As above, the user must also confirm that the meta-attribute name in the scores file is identical to the meta-attribute name in the problem structure files. The numbers that follow the meta-attribute name in each row are assessments that have assigned to the meta-attribute for each alternative being analyzed. Thus, if there are three alternative force postures in a given analysis and meta-attributes are assessed for each force posture on a five-item scale, then there must be 15 values in each row after the meta-attribute name. The first five values correspond to the five ordered levels of the assessment scale for the first force posture, the second five values assess the second force posture, and the final five values assess the third force posture. For example, in Table 5 above, the meta-attribute "Transparent" is rated 4 for force posture 1, 1 for force posture 2, and 2 for force posture 3.

Note that the values appearing in this file are *belief* values for the assessment of a meta-attribute to a certain scale value. For example, on a five-point assessment scale, the vector 0, 0, 0.25, 0.4, 0.3, indicates a distribution of belief of 0.25 to a value of 3, 0.4 to a value of 4 and 0.3 to a value of 5. (Observe that belief totaling 0.05 is unassigned to any value, indicating a certain level of ignorance with respect to the assessment of this meta-attribute.) Belief values must be non-negative and must sum to a value no greater than 1. The values shown in Table 5 are point estimates because each meta-attribute is assessed completely to a single value. Meta-attribute assessments must be in this form in order for the SAW algorithm to be used.

Policy objective weight vectors

As described above, the CANS policy objective analysis has been divided into nine separate problem structure files that are entered into the ATOM DSE. When presented with multiple problem structure files in the context of a single analysis, the R script combines all the policy objectives, intermediate elements and dimensions, and meta-attributes into a single, comprehensive network. To do this integration the user must specify how each of the individual problem structures contributes to the overall evaluation of the problem. Currently, this specification is defined using a CSV text file that must be created manually using any software that can save to a CSV text file (e.g., Microsoft Excel, SimpleText). The content of a sample policy objective weight vectors file is shown in Table 6. Note that if the problem is presented using a single problem structure file, then the weight vectors file is not required.

Table 6. Sample policy objective weight vectors file in CSV format

```
ASSURANCE for COUNTER PROLIFERATION,d,1,1,1
ASSURANCE for STRATEGIC STABILITY,d,1,1,1
COST,d,1,1,1
DEFEAT_DESTROY,d,1,1,0
DEFEAT_NEUTRALIZE,d,1,0,1
DIRECT DETERRENCE,d,1,1,1
EXTENDED DETERRENCE for COUNTER PROLIFERATION,d,1,1,1
EXTENDED DETERRENCE for STRATEGIC STABILITY,d,1,1,1
RISK,d,1,1,1
```

Each row in the policy objective weight vectors file corresponds to one of the policy objective that appears at the top of the nine separate problem structures. Note that although the R scripts are capable of inferring which nodes in the problem structure are top-level policy objectives, there is no error checking in the current version of the software to verify that the list of items in the weight vectors file matches the policy objectives implied by the problem structure files. The user must confirm that the list of entries in the weight vectors file is complete and correct.

The first entry in each row is the name of the policy objective. As above, the user must confirm that the policy objective name in the weight vectors file is identical to the policy objective names in the problem structure files. The second entry in a row indicates whether the relationship between the policy objective and the overall evaluation is direct (denoted by a lower case “d”, without quotation marks) or indirect (denoted by a lower case “i"). The third entry in a row is a numeric value indicating the weight that has been assigned to that particular child–parent connection in the baseline case. A weight vectors file must be provided whenever the problem has been divided into multiple problem structure files, and the first three entries must appear in each row of the weight vectors file. Subsequent entries represent additional top-level calculations that the analyst would like to compute during the analysis. The additional entries are optional.

The example given in Table 6 shows one aggregation across all top-level objectives (the baseline case), one that deletes DEFEAT_NEUTRALIZE from the analysis and includes all others, and one that deletes DEFEAT_DESTROY and includes all others. The objectives included for all of these overall assessments are equally weighted.

HTML resources

The *html_rsrcs* folder contains several files that are used when creating the HTML output at the end of an analysis. This folder and its contents must be available in the same directory as the `ATOM_WEB_OUTPUT.R` script or the script will fail to run.

Output

When the ATOM DSE script is initiated it immediately creates folders on the host system into which the output from the analysis will be saved. These folders are located in the *output* folder that should already exist in the ATOM DSE directory as described above. Inside the *output* folder the R script will create a new folder with the name provided by the user in the TITLE parameter of the configuration file (see above). Inside that folder the R script creates a series of folders that are named with a time stamp denoting the time the analysis was initiated. By organizing the output in this way, multiple runs of the same basic configuration can be grouped together according to the analysis TITLE. A list of the files and folders saved to the time-stamped output files is shown in Table 7.

All output from an analysis is placed in the time-stamped folder. A collection of HTML files is stored in a folder called *html*. The *ATOMresults.html* file is loaded into the default browser automatically when an analysis is completed. To review the output at a later time, the file can be reopened from Windows Explorer. The configuration file, problem structure files, meta-attribute scores file, and policy objective weight vectors file are copied into an *input_data* folder during each analysis so that a complete record of the initial conditions is available for immediate and unambiguous reference alongside its associated output.

Table 7. ATOM DSE output files and folders

```
ANALYSIS RESULTS
    ./output/TITLE/TIMESTAMP/SAW_grades-baseline.csv
    ./output/TITLE/TIMESTAMP/ER_grades-baseline.csv
    ./output/TITLE/TIMESTAMP/Overall_Evaluations-Branch_Weight_Variations.csv
FINAL R WORKSPACE
    ./output/TITLE/TIMESTAMP/TITLE-TIMESTAMP.Rdata
FOLDERS
    ./output/TITLE/TIMESTAMP/html
    ./output/TITLE/TIMESTAMP/input_data
```

Three CSV files and one Rdata file are saved in the time-stamped output folder in addition to the two folders described above.

The *SAW_grades-baseline.csv* file and the *ER_grades-baseline.csv* store the scored assessments of the meta-attributes and the computed assessments of the policy objectives and all intermediate elements and dimensions for the simple additive weighting and evidential reasoning algorithms, respectively. The *Overall_Evaluations-Branch_Weight_Variations.csv* file is only included if more than one branch weight vector is specified in the policy objective weight vectors file. (Baseline assessments of the overall evaluation are stored in the SAW and ER grades baseline files.) The *Rdata* file saved in the time-stamped output folder is a complete copy of the R workspace at the end of an analysis.

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