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Sandia National Laboratories

Behavioral Influence Assessment (BIA)

DYMATICA

Dynamic Multi-scale Assessment Tool for Integrated Cognitive-behavioral Actions

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Modeling & Assessment

DYnamic Multi-Scale Assessment Tool for Integrated Cognitive-behavioral Actions

U.S. DEPARTMENT OF ENERGY

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DYnamic Multi-Scale Assessment Tool for Integrated
Cognitive-behavioral Actions

What is DYMATICA?

DYMATICA (DYnamic Multi-scale Assessment Tool for Integrated Cognitive-behavioral Actions) is a computational approach to help decision makers better understand and anticipate likely responses and decision calculus of groups and individuals to geopolitical situations. DYMATICA models are designed to simulate geopolitical, psychosocial, and economic phenomenon subject to key physical constrains and conditions.

A unique aspect of the DYMATICA modeling framework is that it is designed to quantitatively represent interactions between key actors to indicate likely outcomes over time. Data and information from subject matter experts (SMEs), economic data, and other relevant inputs are used to populate causal, dynamic mathematical models that use a theoretically based cognitive framework. This results in assessments that enable rich exploration of outcomes under a variety of conditions.

History of modeling at Sandia National Laboratories

Since its inception, Sandia National Laboratories[1] (SNL) has been the engineering Science and Technology (S&T) laboratory for the U.S. Department of Energy. One of its primary responsibilities is to ensure that the U.S. nuclear arsenal is both safe and reliable though modeling and simulation (M&S). In fulfillment of this responsibility, SNL has become the premier laboratory for Uncertainty Quantification (UQ), risk assessment, and Verification & Validation (V&V) of computational models. This same responsibility has made integrated system engineering and complex systems-of-systems analysis a SNL priority. In the past 25 years, SNL has expanded its research and development (R&D) mission to include a much greater national security emphasis. This includes the establishment in 1999 of a Cognitive Science and Technology focus area that emphasizes the R&D of PMESII[2] type models. This program has approximately 75 staff members spread throughout SNL.

The DYMATICA effort is a product of this investment. It started as a modest effort in 2008 and has grown to include a number of technically diverse assessments. Since 2008, approximately 14 DYMATICA models have been developed. These models represent a variety of topic domains and country regions from around the world, including countries from Africa, Asia, Europe, and South America. The assessment domain includes cyber activities, deception activities, deterrence activities, internal stability, migration, and propensity for aggressive behaviors. Funding organizations include the Department of Defense, the United Kingdom's Ministry of Defence, and the intelligence community, as well as SNL through its internal Laboratory Directed Research and Development program.

How can DYMATICA help analysts?

DYMATICA can help organizations develop, understand, and compare likely effects of potential courses of action (COAs) under a variety of geopolitical scenarios. It supports hypothesis generation and COA development, analysis, and comparison, while accounting for uncertainty in the environment. DYMATICA also enables comparison and integration of views from multiple SMEs in a common, decision theory-based format.

DYMATICA assessments have provided both intuitive (serving to help corroborate the modeling outputs with analyst knowledge) and non-intuitive outputs. In each case, DYMATICA was able to provide insight that was considered valuable to the customer. The output is intended to support existing assessment methods by providing insights into interactions and influences that can affect the outcome of a situation. As important, the modeling platform also supports insight into interactions and influences that are not likely to affect the outcome of a situation. As such, DYMATICA can provide analysts with a more effective means to assess various scenarios for potentially unexpected outcomes.

How is DYMATICA different from other capabilities?

Other capabilities focus on examining societal contagion effects, broad-level social dynamics, or social network trends. These types of capabilities enable general assessments of societal influences. While DYMATICA can use this type of information, its strength is its ability to quantitatively capture cause-effect theories generated by one or multiple SMEs that have previously existed only in explanatory form. These theories can be tested for consistency with physical limitations and historical and developing situations under uncertainty. Unlike Bayesian techniques or discrete event simulation, the elements are linked in a non-linear, system dynamics model, informed by culturally relevant decision theories.

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[1] Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly-owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000

[2] Political, military, economic, social, infrastructure, and information systems

What type of assessment output does DYMATICA produce?

A typical DYMATICA assessment shows how different scenarios and COAs are likely to affect key outcomes (subject to a variety of causal hypotheses) over time. Depending on the situations of interest, these outcomes may be geopolitical (such as interactions between countries), at the group level (such as political leanings of various groups, or tendencies of groups to engage in conflict or social unrest or to support U.S. actions), and individual level (such as decisions made by leaders). Output can also be non-cognitive (such as resource availability or economic trends). Structural and parametric uncertainty can be incorporated to demonstrate the range of likely outcomes given a variety of potential circumstances.

How long does it take to develop a DYMATICA model?

Model development is largely dependent on the questions being addressed, the level of detail desired, and the type of analysis. Receiving an assessment result for a new, closely related question of existing models could take hours to days. Studies making heavy use of previous models may take a few weeks, while deep assessments involving new questions, further detail, and the modeling of new countries or assessment domains can take several months to multiple years. Efforts are underway to reduce development times and associated costs.

Why our approach is credible

The DYMATICA structure and process are based on a specific combination of well-established psychological, social, and economic theories of decision making, as well as established techniques in knowledge elicitation, statistics, system dynamics modeling, uncertainty quantification, and sensitivity analysis. Computational social modeling is not an exact science; our goal is to improve understanding of likely outcomes in situations of importance to our customers, allowing for higher confidence in intelligence analysis, along with COA development and comparison. Organizations within the DoD and DOE have funded a variety of DYMATICA projects to assess response dynamics in geopolitical, space, military, counter-terrorism, and cyber domains. Our customers have underscored the value of insights gained from these models, as well as the value of improved clarity and understanding of potential inconsistencies or blind spots in conventional thought.

The DYMATICA development process and theoretical background

The process of developing a DYMATICA assessment model involves 10 main steps:

1. Develop key intelligence question with customer
2. Select scope and granularity of assessment with customer
3. Perform extensive literature review
4. Develop systems-level conceptual model (in diagram form) and prototypical models of interactions and influences
5. Perform systems-level and decision-level elicitation from experts
6. Develop dynamic, multi-scale computational model of PMESII influences
7. Run model with simple key feature
8. Falsify or retain, improve, move on
9. Analysis: scenarios, interventions, sensitivity, and uncertainty, risk
10. Dynamic visualization and delivery

The first step in the development process is to determine, with the customer, the overarching question that is important to the customer and/or end user. This typically involves working with various producers and consumers of information to craft the broad-level questions and sub-questions that DYMATICA will assess. The overarching question will help scope and constrain the model so that it is both tractable and useful.

The next step is to determine, with the customer, the granularity for the assessments. This includes the time horizon (the complete span of time the model will simulate and assess, which could be several days to several decades) and the time resolution (the amount of simulated time for each assessment step, which could be simulated hours to months). In addition, from the overarching question it is determined what counties, organizations, individuals will be included in the simulation.

Once the granularity is determined, an extensive literature search and review is performed. This task supplies the modeling team with enough information to properly ask subject matter experts specific questions related to the system of interest.

This process leads to the construction of what is known as a causal loop diagram (CLD). The CLD is used to visualize potential interactions and influences between entities (groups, organizations, leaders) of interest and their environments. These diagrams are considered to be dynamic hypotheses of the structure underlying the system of interest. CLDs are used to elicit information from SMEs regarding interactions and influences. This process is typically iterative, with SMEs reviewing the CLDs and recommending modifications where needed. This process continues until the SMEs are satisfied with the CLDs.

Through the process of creating CLDs and working with SMEs (and often with customers), we can determine if elements within the model would benefit from higher resolution representations. For example, if a society that is being modeled contains several key actors (such as political parties, religious/social groups, etc.) that drive a significant percentage of the interactions, a more detailed representation of these actors might prove useful. Higher resolution representations are modeled within a DYMATICA 'knowledge structure.' One can think of a knowledge structure (KS) as scaffolding for the organization of socio-cognitive processes underlying decision-making, as well as the actual content of that knowledge with respect to a modeled individual, type of individual, or group of individuals. A KS describes the relationships that lead from the marshaling of relevant stimuli in the form of "cues" to the performance of probable behaviors of modeled entities. It incorporates very specific cognitive information such as cognitive perceptions, motivations, attitudes, emotional states, and potential behaviors associated with particular situations. Importantly, this information is structured in a manner that should reflect the processes underlying both highly deliberative and highly reactive human decision-making—taking into account behaviors associated with what is considered both "rational" and "irrational" thinking. This typically includes capturing particular biases, cultural thinking, general practices, and the frequency and recency of behaviors.

Unlike a general database of information, a KS links cognitive information in a manner that is consistent with psychological, social, and behavioral economic theories of human decision-making. The theories that are most prominently represented in a KS are: 1) the model of recognition-primed decision making (RPD) [1]; 2) the theory of planned behavior (TPB) [2]; 3) an extension of theory of planned behavior called the model of goal directed behavior (MGB) [3]; and 4) cognitive dissonance theory (CDT) [4]. The listed theories describe how people make decisions when faced with various situations. RPD focuses on how relatively quick decisions are made based on interpretations of external cues. The TPB focuses on how decisions are made based on prevailing attitudes, social norms, and perceived behavioral control, and mediated by intentions.

The MGB extends TPB by adding emotional affect, desire, recency, and frequency variables. CDT focuses on how cognitive/behavioral discrepancies can affect views towards one's behavior. Integrating the described theories into a single framework can be achieved because each theory generally complements the others. That is, RPD (and other related theories) regard how stimuli affect cognitive appraisal via perceptions of the environment. Cognitive perceptions can then trigger specific attitudinal-emotional beliefs that will help frame the situational context. Social norms and the perception of behavioral control contribute to the desire (which we call motivation), and ultimately the intention, to perform some type of behavior. This cognitive process is discussed indirectly in the TPB and is prominently featured in the MGB. Broader theories, such as prospect theory, complement these theories as well.

Information collected from SMEs is then represented within the DYMATICA model. A DYMATICA model uses system dynamics to simulate interactions between cognitive entities in the context of a problem of interest. These models consist of cognitive model sectors, which use environmental cues to determine behaviors for each cognitive entity of interest, and world model sectors, which include all non-cognitive elements in the simulation (such as economics, resources, or population growth). An assessment begins with a scenario, often including an initiating event associated with certain cues. Cognitive entities interpret these cues as cognitive perceptions, determined by linear weighted sums of cues with coefficients based on the beliefs of each entity. Entities form expectations about the world based on their cognitive perceptions. The normalized difference between expectations and perceptions is discordance.

Each entity calculates an intention utility, or perceived benefit of taking the corresponding action, for each potential behavioral choice. Intention utilities are linear weighted sums of cognitive perceptions, expectations, and discordance, with weights influenced by the entities' cognitive resources (perceptions, attitudes, perceived social norms, and perceived behavioral control). These weights are determined by SMEs, literature, or other data, and may be different for each entity. The model uses qualitative choice theory (QCT) [5] to select the intentions that each entity will pursue. The model's instantiation of QCT uses a multinomial logit function to determine either the probability of selecting a particular behavior from a set (for individuals) or the fraction of people that will select that behavior (for groups). In situations where emotion affects the magnitude of an intention, the model determines amplification using a linear weighted sum of perceptions, expectations, and discordance. Weights for amplification equations are based on positive and negative emotions, and are determined by SMEs, literature reviews, or other data. Intention evaluations are multiplied by amplification to determine indicated behaviors of each entity. Actions, or physical realizations of behaviors, are delayed versions of these indicated behaviors. Both actions and world model outputs (which can also depend on actions) can act as cues for cognitive entities in subsequent time steps.

Once the initial model is built, it is assessed to determine if the results are consistent with SME opinion and with current and previous observations of entity behaviors (if applicable). This process continues until all parties are confident that the output provides useful insight given the constraints of time, information, and scope. Results are dynamically visualized in a graphical user interface.

Historical data and SME information can be used to calibrate and parameterize DYMATICA models. Uncertainty in the data is explicitly characterized, and uncertainty quantification identifies uncertainty in model results. This process provides confidence intervals on the results of the model analyses that test interventions. By simultaneously performing uncertainty quantification for model parameters and potential interventions, DYMATICA can determine the portfolio of interventions that have the highest (quantified) probability of success despite uncertainty. It can also quantify the risk of an intervention not performing as anticipated. Additionally, DYMATICA can perform sensitivity analyses to determine what minimal additional information is needed to maximally reduce uncertainty and further assure the proposed interventions produce the desired outcome throughout the time horizon of interest. Moreover, because the model is causal, decision-makers can reach back into detailed results of the simulation to independently evaluate the nuanced processes that caused the anticipated outcomes and find leverage points that would be maximally effective at altering these outcomes.

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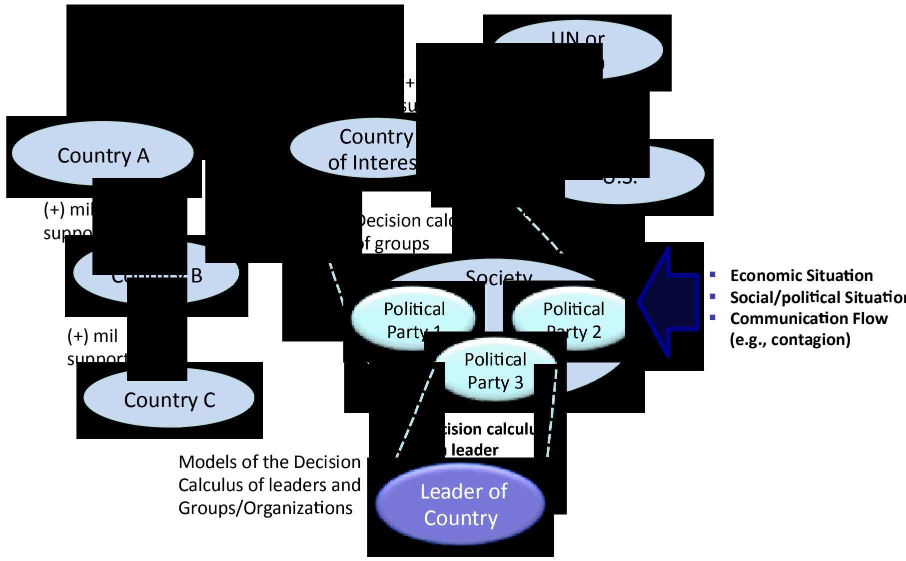
Two assessment examples

Better anticipating the decision calculus of countries to potential events and capabilities

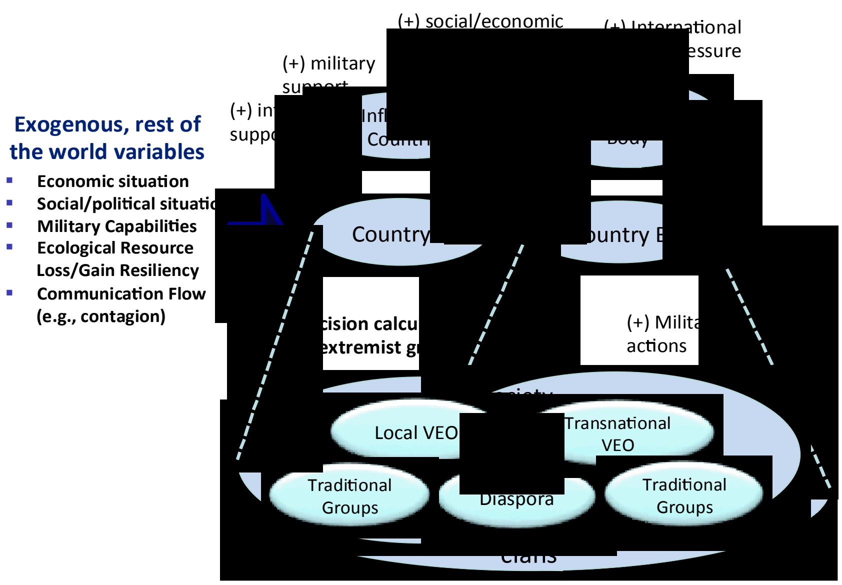
DYMATICA models have assessed different geopolitical and socio-cultural narratives regarding the internal perceptions of a country's status, capabilities, and hegemony over other countries within a region. This involves the modeling of PMESII factors associated with a country's economic and military capabilities, as well as their self-perceptions, behavioral tendencies, and internal political dynamics – including specific social and political organizations, along with specific leaders.



The intent of these efforts is to better understand and anticipate competing sociopolitical dynamics within a county along with certain narratives employed to carry out specific objectives. The focus here is to enable better forecasting of political/social/military trends shaping the future operating environment and its military implications with quantifiable uncertainty. This effort is addressing such questions as: How do changes in economic circumstances, military capabilities, geopolitical positioning, and sociopolitical conditions affect a country's stability and ability to project power over the next ten years?

Better anticipating the decision calculus of violent extremist organizations to potential courses of action

DYMATICA models are assessing how (and when) perturbations within different indigenous and diaspora communities, logistical networks, and ecological systems (e.g., refugee migrations, disasters) could affect the behaviors of specific national and transnational violent extremist organizations (VEOs), societies, and governments over time. This involves modeling PMESII factors associated with specific VEOs, including their economic and military capabilities, and their interactions with local societies and governmental organizations.



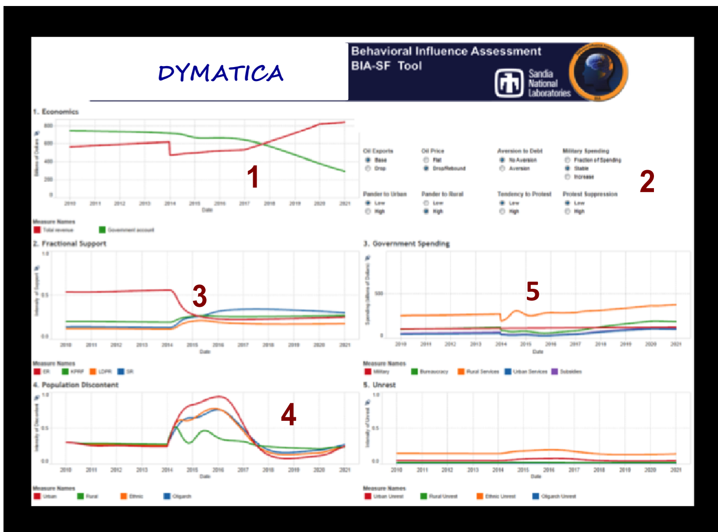
Recent uprisings and social collapses within international areas of concern have highlighted the need to adequately anticipate likely changes in behaviors in response to shifts in beliefs and attitudes of a population, along with the emergence of economic, logistical, and ecological failures. The focus of this effort is to better address such questions as: How do VEOs influence areas within certain regions? What type of activities could strengthen pro-Western government within a region? How can we better understand and anticipate the behaviors of VEOs over time?

Adapting DYMATICA for other projects

Besides the two examples mentioned above, DYMATICA has been used to assess questions about conflict escalation (including kinetic, cyber, and hybrid conflicts), country stability, societal effects of resource depletion, the effect of certain actions on populations' affinity for the U.S. or other Western organizations, responses to and effectiveness of military technologies under consideration, and the effect of information sharing on team interactions and effectiveness.

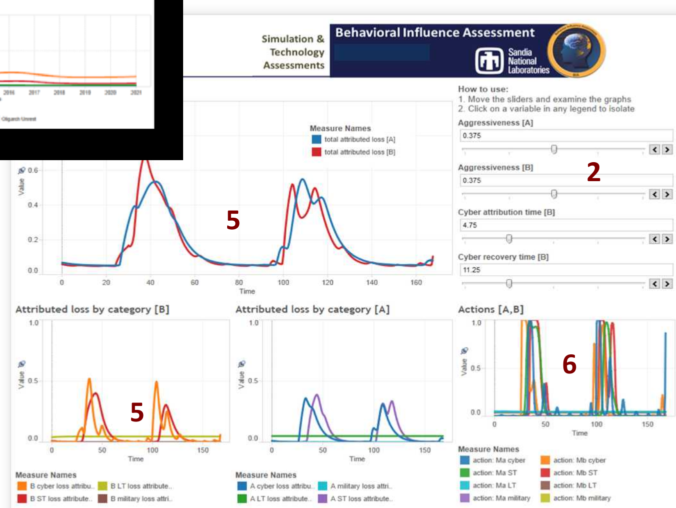
Typical assessment results

DYMATICA assessments are tailored to fit the needs of the customer. Examples of previous assessment are shown below. These examples are meant to broadly demonstrate the type of assessments DYMATICA is best suited to perform.



Can dynamically modify conditions:

- Generate "what if" course of action/event configurations (1)
- Modifications of the general conditions of the simulation (2)



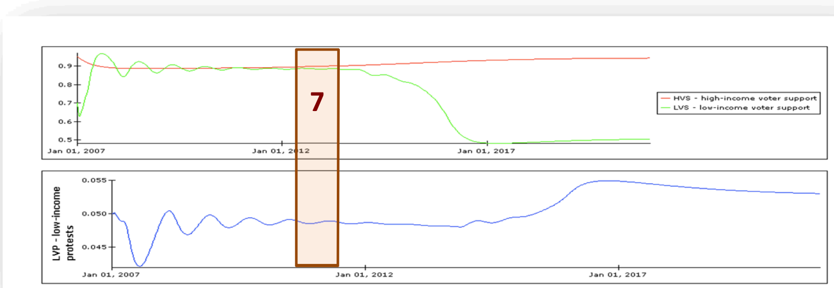
Can generate assessments that analyze:

Country Stability Projections:

- Change in political support of leaders over time (3)
- Population discontent with government over time (4)

Conflict in Region Projections:

- Military, political, economic vulnerabilities of countries over time (5)
- Courses of actions between countries over time (6)
- The potential affect of a COA for a specific period of time (brown box) on different group behaviors (7)



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