ANTICIPATING THE POTENTIAL RANGE OF BEHAVIORS FOR INDIVIDUALS INTERACTING WITHIN SOCIETIES

Michael L. Bernard[1], George A. Backus[1], Asmeret Bier Naugle[1], Robert F. Jeffers[1], and Regan W. Damron[2]

[1]Sandia National Laboratories, Albuquerque, NM, USA

[2]Strategic Foresight Branch, U.S. European Command Stuttgart, Germany

Abstract

This chapter describes a theory-based analytical capability to enable analysts to better assess the influence of events on groups interacting within a country or region. These events can include changes in policy, man-made or natural disasters, war, or other changes in environmental/economic conditions. This chapter includes a discussion of: 1) underlying psychological, social, and economic theories that are synthesized within its structure; 2) inclusion of data and expert opinion into the modeling structure; 3) methods used to computationally instantiate theories and data/opinion; 4) types of assessments that are generated; and 5) the implications of these assessments in comparison to current events.

Key Topics

- General types of computational modeling: System dynamics, agent-based, and hybrid models
- Introduction to a hybrid modeling example: DYMATICA computational model
- Macro- and micro-level decision theory representation within DYMATICA
- Computational structure of DYMATICA and the process of representing behavior
- Applying DYMATICA to a real-world example and the Megacities narrative

Introduction

> "Simply stated, the lesson of the last decade is that failing to understand the human dimension of conflict is too costly in lives, resources, and political will for the nation to bear. Once a conflict commences, it is already too late to begin the process of learning about the population and its politics. The optimal condition is

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> for our leaders to have the ability to influence budding conflicts "left of bang[1]," that is, *before* tensions turn violent. Left of bang, policy options are more numerous, costs of engagement are lower, and information flows more freely to more actors. After a conflict begins, options decrease markedly, the policy costs rise rapidly, and information becomes scarce and expensive… A new concept should seek to explain how populations understand their reality, why they choose either to support or resist their governments, how they organize themselves socially and politically, and why and how their beliefs transform over time" (Flynn, 2012, p. 2).

A common obstacle associated with the effort to better assess potential behaviors within different societies is the shear difficulty in comprehending the population's dynamic nature, particularly over time and considering feedback effects. Obtaining better insight with regard to how populations understand their reality and respond accordingly is *particularly* difficult. These obstacles are becoming more problematic as small groups, and even individuals, are increasingly able to harm large segments of society. Thus, determining what is actually achievable in obtaining better insight into how societies perceive their environment, make decisions, and ultimately behave is becoming increasingly important. Efforts to achieve this insight have employed a number of qualitative and quantitative modeling techniques. This chapter discusses a quantitative approach to simulating human behavior in order to better assess various conflict- and stability-focused scenarios. More specifically, this chapter focuses on the development of methods to quantifiably address prevailing dynamics and unintended higher-order consequences of events on populations over time. It is not, however, focused on predicting specific individual or group behaviors at some particular time.

[1] More formally known as the "shaping" or "preoperational" phase before a conflict.

Computational Modeling: System Dynamics, Agent-Based, and Hybrid models

To most effectively understand conflict and stability, models assessing sociocultural influences on behaviors should incorporate causality, dynamic tendencies, and some specification of decision-making processes. System dynamics and agent-based modeling techniques can incorporate these characteristics to address issues relating to conflict and stability. System dynamics models (Forrester 1961; Ford 2009; Sterman 2000) use difference equations, determined by causal structure, to dynamically simulate systems of interest. They are generally constructed using stock and flow systems (described below) with carefully specified mathematical relationships between variables. System dynamics models are generally not strongly driven by exogenous factors, although exogenous factors often do play a role. The models account for feedback dynamics and time delays in the system.

While system dynamics models tend to be most useful for broad-level, aggregated systems assessment, agent-based models (Macy & Willer 2002; de Marchi & Page, 2014) are useful for simulating interactions between individuals and assessing complex emergent group behaviors over time. In comparison to system dynamics, agent-based models tend to use simpler descriptions of decision-making processes, but more complex networks of individuals. They also allow for probabilistic interaction, while system dynamics models are generally deterministic.

System dynamics and agent-based models have some similarities that make them particularly applicable to sociocultural modeling, creating opportunities for hybrid simulation. Both types of models can be used to simulate decision-making processes where interactions between people or groups are fundamental to the simulation outcomes. While agent-based models tend to focus on individual behaviors and system dynamics models tend to focus on aggregate behaviors, there are no hard rules delineating the granularity for each type of model. In some cases, combining system dynamics and agent-based techniques can improve simulations by incorporating individual and emergent behavior with structural and group dynamics.

Theoretical Orientations of Computational Modeling

The model's theoretical orientation is every bit as critical as the computational approach in determining the assessment's overall direction and scope. Robust theories that have been developed and empirically tested across social, religious, and political boundaries are found within anthropological, economic, political science, psychological, and sociological disciplines. Incorporating theory within computational models can enable the theories and data to be interrogated in a much more precise manner. Since each discipline typically has a different focus, integrating multiple theories across these foci potentially allows the model to address a wider range of behaviors. For instance, anthropology addresses cultural behavior aspects, economics (or more precisely, behavioral economics) addresses how decision-making affects behavioral choices, psychology addresses the mechanisms and processes underlying decision-making, political science addresses how individual preferences are aggregated and expressed under various institutional and systemic constraints, and sociology addresses the processes underlying group interaction and potential conflict within societies.

Modeling Example: Hybrid Computational Models

An example of a computational model that has incorporated system dynamics and agent-based approaches, as well as several theoretical methodologies, is the Dynamic Multi-scale Assessment Tool for Integrated Cognitive-behavioral Actions (DYMATICA) modeling effort within Sandia National Laboratories' (SNL)[2] Behavioral Influence Assessment program. The objective of this hybrid modeling approach is to have greater decision and behavioral insight by providing a modeling structure that represents interactions among groups within societies. The basis for the approach is to assess the dynamics and key psychosocial, geopolitical, and economic processes underlying how people make

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decisions and express behaviors over time. Included in these simulations are behaviors that affect the decision-making of others, creating complex feedback loops within and between individuals and groups. Each simulated behavior is a function of individual psychosocial characteristics (described below) along with environmental and group dynamic factors. This effort's goal is to inform planning processes and decisions that minimize the likelihood of undesirable consequences by providing a more systematic (and thus, replicable) analysis of group perceptions, intentions, and behaviors, as well as the environmental variables that bear upon their interactions (Bernard, et al., 2014; Bier & Bernard, 2014). To help achieve this objective, this program is developing models that synthesize data-supported, behavioral-economic, political, psychological, and sociological human behavior theories. This synthesis is further supported by an independent, theory-based analytical assessment of historical socioeconomic data. As it is designed to inform rather than predict, DYMATICA focuses on examining likely dynamic repercussions of actions, not on generating specific behavior estimates. The result is a unified framework that connects the multiple scales of human behavior (from individual to societal interactions) to the external (geopolitical, physical, and socioeconomic) world.

Computationally, the DYMATICA structure consists of a modeling framework, model simulators, and an analysis approach. The current structure allows for assessment of models across different domains (i.e., different countries, groups, individuals, and scenarios of interest). For example, Figure 1 shows a simplified conceptual representation of a hypothetical DYMATICA structure that involves the modeling of two interacting groups and several leaders. Exogenous inputs to the model (e.g., global economic factors and general population support) influence the dynamic interactions within and between the entities. Each simulated behavior is a function of psychological characteristics along with environmental and group dynamic factors. This enables the assessment of group behaviors as the groups react to other's perceptions and world conditions.

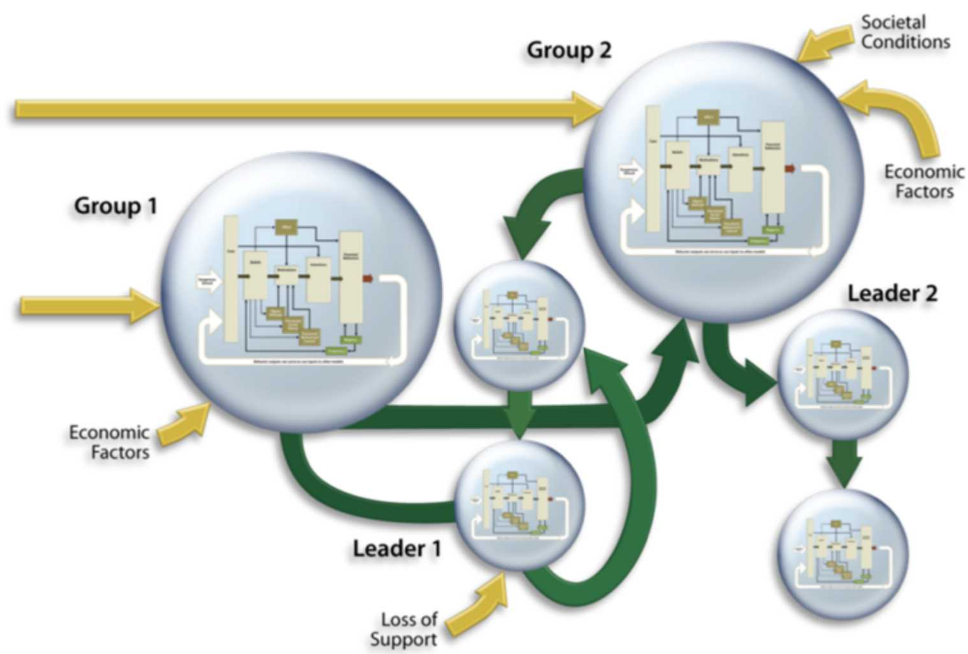

Figure 1. Conceptual diagram of the full systems view of a hypothetical application of DYMATICA Methodology

Problem Question to be Modeled

The modeling process begins with a problem question to be addressed. Modeling a problem helps to bound the model, focus the list of auxiliary questions, and define project tasks. The scope of the problem will help to determine the level of detail in the model; a very broadly defined problem will usually result in a high-level model, whereas a more targeted problem can lead to a more detailed model. The time horizon, groups and/or individuals to be modeled, and major variables of interest are typically identified at this point. The general scope of the model structure is determined based on the overarching question(s). At this stage, the process of generating possible sub-questions begins. Vetting the sub-questions with an analyst consumer helps to further refine this structure.

Knowledge Acquisition Process

The process of populating the model begins at a macro level. At this level, we seek to understand the essential human influencers in the system and begin to identify the fundamental dynamics within and between entities. Sub-system structures may also be included to represent non-cognitive processes, such as economic or resource dynamics within the broader system. The specific expressions pertaining to each influencer, and what behaviors each influencer can invoke, is determined through the use of subject matter expert (SME) guidance and available data. SMEs can hypothesize relevant concepts and abstract notions that may not be apparent from available data. Analytical methods can also enable estimation of how the hypothesized behaviors could occur based on knowledge of a group's behavior in other circumstances.

As the model is developed, SME guidance, data, and report information is used to add specificity to the structure. From the overall question it is determined what should be modeled at a more macro, social-systems level and which entities (individuals, groups) should be modeled at a more detailed or micro level. Macro information typically pertains to societal systems that include economic and behavioral trends, whereas micro information pertains to a group's or an individual's decision making process.

The micro information is documented via the DYMATICA Knowledge Structure. The Knowledge Structure is consistent with specific, decision-making psychosocial theories. It is organized in a manner that characterizes the decision processes of individuals and acts as scaffolding for the organization of psychosocial processes underlying decision-making. The intent of this structure is to record the elicited SME knowledge content with respect to a modeled group of individuals. In doing so, it captures information such as cognitive perceptions, motivations, norms, and potential behaviors. This information is treated as a hypothesis with regard to the actual decision making process of the entities of interest.

Call-out 1

The process of knowledge acquisition generally includes the initial elicitation of knowledge from a SME, as well as the explication, coding, and presentation of knowledge (Cooke, 2007). These methods can, however, vary in accordance with the specific needs of the task and the degree of rigor imposed on them. Currently, there are numerous techniques and tools to help facilitate the elicitation and structuring of knowledge within expert-type systems—particularly those that focus on technical processes, such as mechanical troubleshooting (Shaw & Woodward, 1990). These techniques range from unstructured and structured interviews to the development of ontologies and entity-attribute grids.

Accounting for SME Bias

Dealing with SME bias will always be a challenge. Each SME brings with them educational, cultural, and political biases that can influence their interpretations of a situation, society, group, and/or person. This can provide important insight, but also has the potential to skew the elicited information. The Knowledge Structure enables comparison and integration of views from a variety of SMEs in a common format. This is important for incorporating multiple SME views regarding the decision making of a specific entity. Because the output from each SME can be compared to that of all other SMEs, the structure can be used to assess similarities and differences between SME opinions and to examine how knowledge from multiple experts converge. We typically want multiple SMEs that have different cross-cultural expertise to include multiple points of view. Each SME Knowledge Structure is then treated as a separate instantiation within the DYMATICA model. The spread of simulated outcomes will consequently cover all elicited opinions, where common and unique views can be separately assessed for consistency with actual behaviors as they unfold. Unique views that do not contribute to the assessment's accuracy can then be devalued. It is also possible that unique views can be highly consistent with certain observed behaviors. If so, greater weight can be placed on these views. This process is accomplished through the use of quantitative techniques such as sensitivity analysis and uncertainty quantification, which can be designed to compare the accuracy of each SME's knowledge contributions across time. When data cannot identify the most appropriate SME perspectives, the ensemble of perspectives can generate an uncertainty envelope as an output. Analysis of intervention options then utilizes that envelope to determine confidence in those intervention's outcomes[3].

[3] A greater description of the DYMATICA Knowledge Structure is discussed in Bernard (2015).

Macro-Level Theoretical Representation

The DYMATICA structure rests upon a synthesis of psychosocial theories that can be: 1) integrated into a representation of behavior; 2) translated into a set of computational equations; and 3) instantiated, tested, and verified using accessible data. The intent is to use robust theories that apply across behaviors and societies to describe innate human characteristics. While no theory has been empirically tested across all cultures, certain theories have been used across a large number of societies and seem to explain some general human tendencies.

In parallel with psychosocial theories (described below), a set of behavioral economic theories—also extensively evaluated with experimental and historical data—have been incorporated into the general DYMATICA framework. It should not be too surprising that the behavioral economic theories mesh well with the included psychosocial theories, since behavioral economics fundamentally describes how people make choices. The theory set describes how behaviors are derived from decisions and how choices are made to determine those decisions. For instance, prospect theory suggests that decision makers negatively weigh potential losses more strongly than they positively weigh comparable gains (Kahneman & Tversky, 1979). The human response to perceived risk lends itself to behavioral responses within computational models. Also, DYMATICA uses a flexible version of the (psychologically framed) qualitative choice theory (QCT) developed by McFadden (1984). This is used to quantitatively capture how individuals make behavioral choices based on how they weigh information, tastes, beliefs, and preferences.

Call-out 2

Prospect theory is a descriptive model of decision making that focuses on factors that help determine the degree of risk one is willing to take. Specifically, how one frames a situation can affect the degree of perceived loss and/or gain one is willing to take. These decisions are evaluated using heuristics regarding the potential value of losses and gains rather than the final outcome. Thus, greater weighting of behavioral tendencies might be placed on groups seeking to avoiding losses (such as in war, finances, etc.) than pursing greater gains (Kahneman & Tversky, 1979).

The robust parameterization of QCT is often based on data readily obtainable in the field. Other techniques can further determine the correct functional representation of the QCT utility formulation for the problem at hand (Keeney & Raiffa, 1976). A key part of the decision process is the filtering of information and the extent to which experience biases the decision process. At a group level, the probabilistic nature leads to a mean-value response because random variation in one direction by a single individual is balanced by the reverse variation of another individual. The enduring population (society) aspects dominate group behaviors. The decision process' transient and stable components are identified by co-integration (also Granger Causality) methods pioneered by Granger (1969). These same methods also ascertain the filtering and delayed-response processes associated with information perception and behavior. These methods and others are summarized in Backus and Glass (2006). Moreover, they can integrate disparate perspectives and information, qualitative as well as quantitative, into analysis and decision support systems. They are also compatible with orthodox macroeconomic assumptions and used for all matter of choices (including those associated with security).

Micro-Level Theoretical Representation

In order to understand and predict our environments, humans attempt to find patterns in stimuli. If relevant, stimuli can be perceived as cues to particular cognitive perceptions regarding one's current environment. Cue patterns may be associated with an existing or potential situation or state. The notion that cues, in many circumstances, can trigger a cognitive perception without the need for extensive deliberation has been proposed by researchers such as Klein and colleagues (1993) in their model of recognition-primed decision-making (RPD).

Individual differences in culture and experiences may cause the same stimuli to be interpreted differently, thus stimulating different cognitive perceptions within individuals (Wisniewski, 1995). For example, groups that share similar cultures and/or religious backgrounds may generally have common cognitive perceptions that differ from other, less similar, groups. These concepts involve the representation of environmental cues and relevant knowledge in a manner that accommodates conceptual pattern recognition.

In DYMATICA, a cognitive perception is considered to be an estimate of some attribute or state in an environment that may affect an existing attitude. When a cognitive perception rises to full consciousness, it will be compared to a cognitive perception "template" that is stored in long-term memory. These templates store semantic self and environmental perceptions and serve to categorize one's perceptions of one's world (Markman, 1999).

Cognitive perceptions may stimulate other cognitive processes such as emotional reactions (which we more broadly characterize as positive and negative valences), attitudes, expectations associated with perceived social norms, and perceived behavioral control over potential behaviors. These things may help stimulate a motivation to perform some specific type of behavior. If the motivation is high enough, it can stimulate an intention or set of intentions to perform some type of behavior (Fishbein & Ajzen, 1975). The intention to perform a specific behavior is typically a function of what is perceived to be actionable. Thus, upon assessing the environment, intentions that are not perceived to be attainable will lose strength while intentions that are perceived to be attainable will gain strength. Moreover, the valence associated with an emotion (low to high positive, low to high negative) can mediate both the selection and degree of risk one is willing to take associated with those behaviors (Bernard & Smith, 2006). The actual behavior that is realized is a function of the intent, associated emotional strength, and the perceived environmental conditions indicating that behavior is indeed actionable. Additional factors that can affect the likelihood of a behavior being realized include how often and how recently that behavior has been previously acted upon. That is, previous behaviors tend to be good predictors of future behaviors (Bagozzi & Kimmel, 1995).

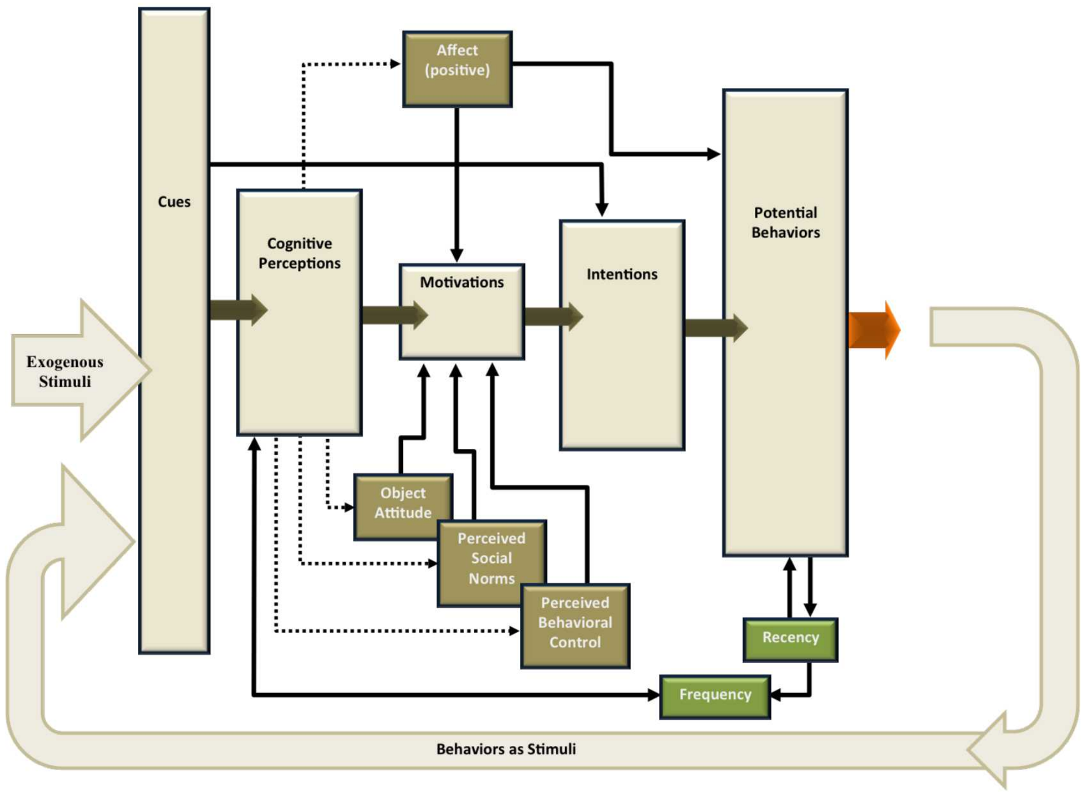

Figure 2. Conceptual diagram of the psychosocial (decision) model

With respect to attitudes, cognitive perceptions are thought to be associations or linkages that people establish between attributes of attitude objects (Fishbein & Ajzen, 1975). An attitude can be thought of as a general and relatively enduring evaluative response to an attitude object, where an attitude object can be a person, a group, an issue, or a concept (Visser & Clark, 2003). This evaluative response generally has some degree of favor or disfavor, approach or avoidance, or attraction or aversion toward that object (Ajzen, 1991; 2005). This is expressed with differences in emotional direction that can be "bifurcated into positive and negative evaluations" (Eagly & Chaiken, 1993, p. 4). A general theoretical model supporting the notion that attitudes and intent are highly associated with behavior is the theory of planned behavior (TPB). The TPB postulates a process in which behaviors are influenced by (a) current attitudes towards a specific behavior, the (b) subjective norms associated with acting out that behavior, and (c) the perception that carrying out this behavior is within the person's control. The combination of these factors forms a behavioral "intention" state, which can serve to drive that person's actual behavior (Ajzen, 1991; Madden, Ellen, & Ajzen, 1992). It is asserted in the TPB that an individual's intention captures the factors that influence some type of behavior, which is indicative of one's effort to perform that behavior.

Call-out 3

The strength of correlations between cognitive elements has shown considerable variability across a number of studies (Ajzen, 2005). However, a major factor causing this is the difference in granularity in measurement between these elements. This is particularly true for attitudes, since attitudes are often not directed toward a specific behavior and, thus, may be very broad in its level of specificity while the measure of behaviors may be very specific. Intentions, however, are typically concerned with a specific behavior and, therefore, are generally more consistent in its level of specificity with behaviors.

The success of the TPB has lead researchers, such as Perugini and Bagozzi (2001), to extend this theory in an attempt to explain a larger percentage of variance associated with behavior. Perugini and Bagozzi's model of goal-directed behavior (MGB) includes the predictor variables of attitudes, positive and negative emotion, subjective norms, and perceived behavioral control, which drive desires. Desires in their model drive intentions[4]. As with the TPB, perceived behavioral control also mediates behavior. In addition, they include the frequency and recency of past behavior, which mediates potential behaviors. Perugini and Bagozzi (2001) argue that individuals take into account both their attitudes and emotion regarding potential achievement or failure with respect to a sought after goal. That is, an attitude is an "evaluative response toward an object or act that, once learned, is triggered automatically" (p. 82). The processes underlying emotion, on the other hand, are "more dynamic and entail self-regulation in response to

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[4] Note, in the MGB, Perugini and Bagozzi chose the more specific term "desire" instead of motivation. DYMATICA uses the more hierarchically expansive term, "motivation" to represent a broader range of drives.

feedback” (p. 82). As discussed above, adding these predictor variables should, in many circumstances, explain a higher percentage of the variance associated with behavior. If so, MGB would further broaden and enhance the TPB by providing greater predictability of behaviors.

Computational Structure of DYMATICA

A DYMATICA model uses system dynamics to simulate interactions between cognitive entities in the context of a problem of interest (see Figure 3). 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 their world based on their cognitive perceptions. The difference between expectations and perceptions is called discordance. Discordance is the normalized difference between perceptions and expectations.

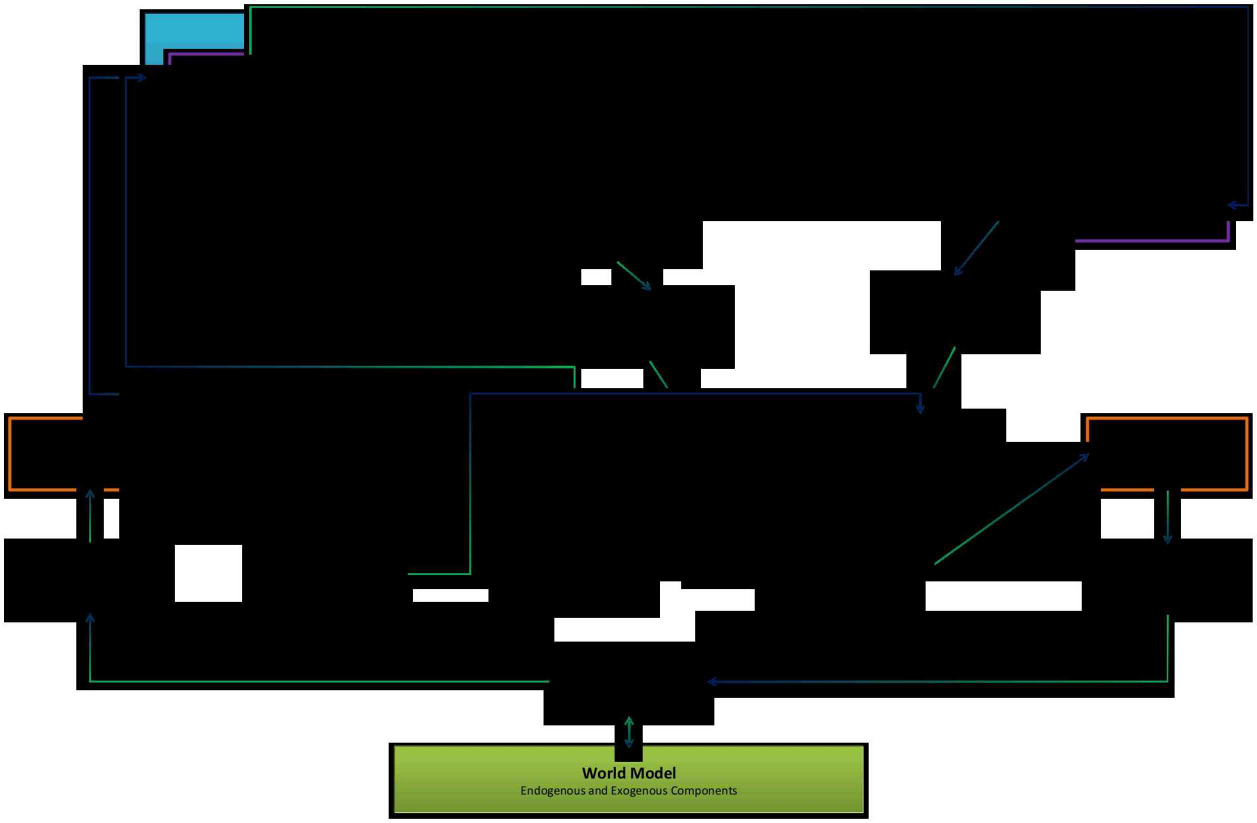

Figure 3: Overview of the DYMATICA structure

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 determined 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 QCT (McFadden, 1982) to select the intentions that each entity will pursue. This is based on a multinomial logit function that determines 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.

The Process of Representing Behavior

Representing potential behavioral responses and counter-responses is first achieved through causal-loop diagramming, which causally relates the interactions included in the model. The causal loop diagram is then mapped to a stock-and-flow diagram that explicitly details the information flow and physical quantities through the system. A key feature is the designation of stocks that represent the accumulation of information, experience, monetary, or physical quantities. These stocks, or "state variables," largely characterize a system's nature and its responses. The change in the value of stocks over time is the "differential" part of the differential-equation approach to computational modeling, which the system dynamics paradigm approximates. The theory's exact mathematical expression is anchored in the accumulation of flow into and out of the stocks. The mathematical expression of the flows comes from a causal interpretation of the theory into the mathematical language. The data determines the parameters that control the progression of the simulated values through time. Rigorous statistical techniques determine the appropriate parameters and the uncertainty associated with their use. This uncertainty can later define the confidence in the results of an intervention analysis.

As discussed above, populating the structure with information is achieved via the DYMATICA Knowledge Structure. For example, circled formulas in the rightmost image in Figure 4 are populated with information, via the Knowledge Structure, shown on the left in Figure 4. As these structures are developed, increasingly more detailed domain information is used to populate the models and to help ensure the Macro-level and Micro-level structures are consistent. That is, this information can be used to further strengthen the overall systems structure. The quantitative data comes from such things as survey polls, economic output reports and projections, and demographics, all of which provide useful information pertaining to perceptions, attitudes, behaviors, and trends.

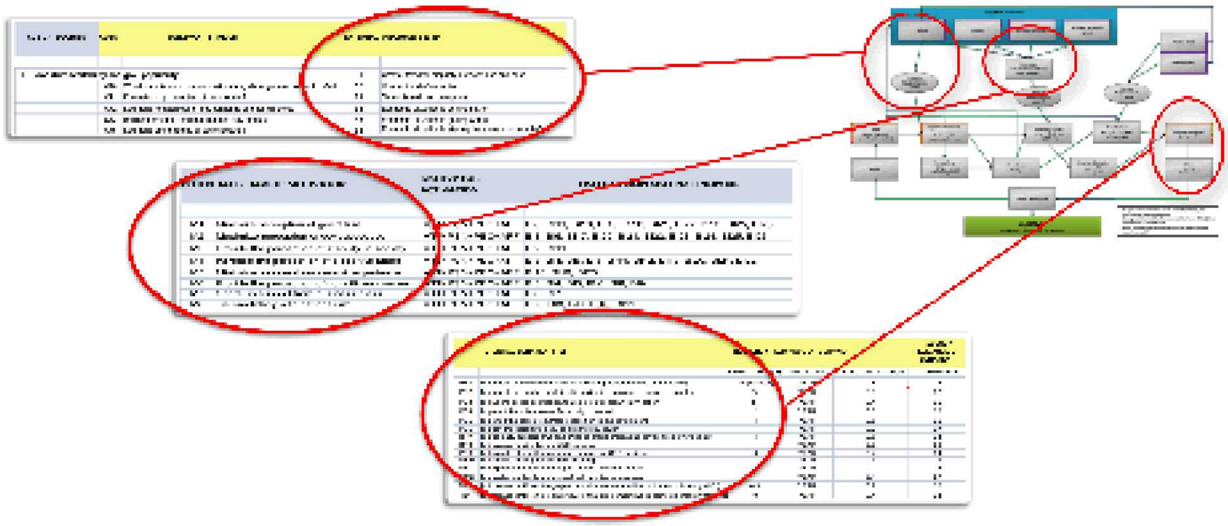

Figure 4. Example of a Knowledge Structure showing cognitive perception, motivation, and potential behavior information

This approach to modeling is made possible by assuming a fixed set of potential behaviors embodied in a representation of the individual or group. The representation contains the preferences and personality characteristics pertinent to the relevant decision-making. While the magnitude of interactions may change, the model does not produce new paths of cognition. All potential interactions are determined via initial model parameterization. Over time, the simulation will be less applicable in that the modeled individuals or groups will be responding to a new set of cues. This will require updating the parameters within the models, either exogenously or endogenously.

Although the relationships between the elements within the model are indeed fixed due to their derivation from the Knowledge Structure, it is possible to vary world model (system-level) inputs over theoretically or empirically appropriate ranges and store the model results at each value (or combination of values, if referencing more than one input variable). This enables end users with little modeling and simulation experience (e.g., analysts) to adjust the levels of the input variables and evaluate changes in the model results without having access to the infrastructure required for a series of computationally-intensive model runs. Being able to adapt the model output allows users to reflect real world changes as they unfold and/or to analyze different potential scenarios germane to the research question, even as the underlying model mechanics remain static.

DYMATICA in Action: Assessing Environmental, Geopolitical, and Societal Factors Influencing Unrest and Government Support.

An illustrative DYMATICA model assessment is presented below. In this example, the model focuses on potential geopolitical tensions arising out of the construction of the Grand Ethiopian Renaissance Dam (GERD) in Ethiopia. Recently, the construction of the GERD has generated tensions between Egypt and Ethiopia over control of the Nile River in Northern Africa. These tensions have the potential to exacerbate existing stresses within Egypt, leading to greater internal conflict[5]. DYMATICA was used to assess how tensions within Egypt might evolve from impacts of the GERD. The interplay between four parties (the Egyptian regime, the military-elite, a more militant Islamist population, and the general population) over an upcoming ten-year period was addressed. Similar to what happened before the Arab Spring, the rise of food prices, which was a strong driver for the unrest leading up to the Arab Spring events, is hypothesized to produce economic stress that could be driven by the GERD, albeit with different political undertones. With this hypothesis in mind, DYMATICA was applied to lend insight to the following questions:

1. How might unrest manifest within Egypt progress? What party would receive the brunt of the blame, given different assumptions about the impact of the GERD?
2. How do different Egyptian economic policies and factors (such as the use of food and energy subsidies, military spending, and external food or energy price shocks) affect the population's response to the GERD?
3. How do Egyptian non-economic policies such as suppression of unrest and government messaging influence how the population will respond to GERD's impact?

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[5] In March 2015, an agreement was signed between Egypt, Sudan, and Ethiopia, providing a base for corporation in the region regarding the GERD.

Call-out 4

This model represents macro-level societal interactions as well as micro-level socio-political entities that are inclusive of various groups within a society. These entities can be thought of as existing within a causal structure where decisions of certain entities define the strength of relationships. By determining the relationships between the entities, a list of potential behaviors, motivations for these behaviors, and cues that would activate these motivations was generated. This set of potential behaviors, motivations, and cues, along with how they are related to one another is the core cognitive input that defines this modeling structure.

Entities and Decisions

The following set of cognitive entities was chosen for simulation as they pertain to the above set of questions. These entities were represented using a cognitive-behavioral modeling structure described above.

- The Regime: Represents a set of high-ranking government officials (which include former military officers). The Regime is primarily interested in improving the Egyptian economy, decreasing the perception of instability by internal and external parties, and maintaining power. The Regime is assumed to have enough influence to decrease the GERD's impacts through diplomacy.
- The Military Elite: Represents high-ranking officials within the Egyptian military and military connected business owners and executives who are motivated to keep their wealthy and powerful positions.
- The Islamists: Represents Egyptian population motivated to increase conservative Islam within the Egyptian government.
- The General Population: In essence, the General Population is everyone else. Both the General Population and the Islamists are quite poor by Western standards. Beliefs include a high sense of

pride and the belief that Egypt remains the regional leader. Motivations stem from distrust of corrupt regimes and distrust of colonial influencers, balanced with a buildup of fatigue from recent instability and economic hardships.

The Model

Cognitive entities interact not only with each other in DYMATICA, but also with the surrounding world. For this effort, the world model represented the effect of food and energy subsidies on finances, government income dependencies, and the balance of protestors and enforcement in the streets. Varying the scenarios to the world model provided insight into how internal and external economic facets may influence future behavior within Egypt. These inputs include: the size and timing of GERD's impact on agricultural production; the size and timing of GERD's impact on energy production; the price elasticity of food and energy supply; external food or energy price shocks; and the efficiency of food and energy subsidies.

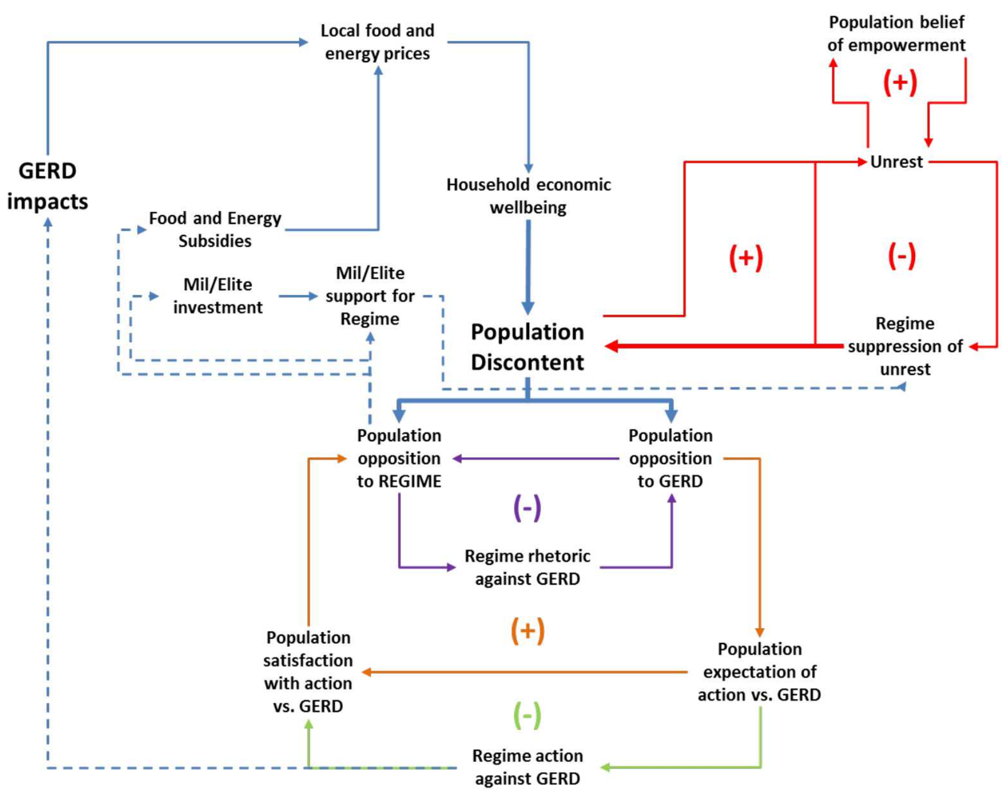

Figure 5. Causal loop diagram of the key hypothesized relationships associated with unrest in Egypt.

Figure 5 shows the multiple feedback loops affecting how population discontent can lead to unrest and opposition toward the current regime. Of particular note are the positive and negative loops toward the right of the diagram. The positive loop most closely situated to population discontent is referred to as the suppression loop, in which the government's decision to suppress unrest directly leads to more population dissatisfaction and more unrest. This loop is dependent on the mechanisms used in suppression, as well as the population's reaction to these methods. Even if the suppression is successful at first, the empowerment loop (in the upper right-hand corner) can lead to long-term escalation of unrest. The suppression loop affects how successful governments will be at quelling unrest in the short-term, while the empowerment loop determines the amount of time a regime has to fix the underlying conditions that lead to unrest.

Household wellbeing, calculated using perceived income inequality, is a direct driver of population discontent. Cognitive entities compare their own discretionary income to that of others in the model. Discretionary income for Islamists and the general population (which are economically identical) is shown in Figure 6. At the beginning of the GERD's potential impact, Egyptians receive a large reduction (nearly 20%) to their discretionary income, which begins to recover as the Regime increases food and energy subsidies. However, the Regime cannot afford these subsidies for the duration of the disruption, and the population's discretionary income begins to decline again. The Military Elite (not shown) experience almost no impact to their discretionary income.

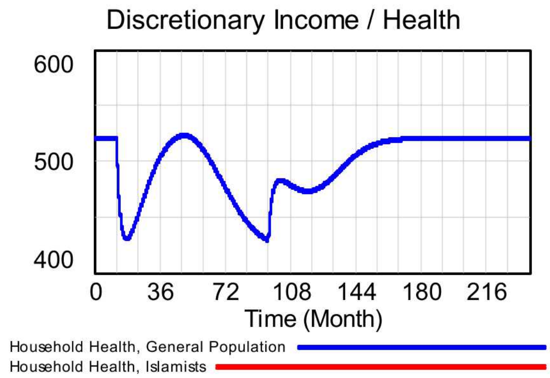

Figure 6. Discretionary income for Islamists and the General Population

In the initial assessment, the Regime is attempting to recover the economy (thus improving discretionary income) by making new investments in materiel supporting the Military Elite, but that will take time to manifest. These investments may include new resource development such as natural gas or mineral deposits, or development of military strength to improve competitive stature in the region. In the meantime, they increase food and energy subsidies, and attempt to negatively direct public opinion toward the GERD and away from the Regime. This economic and emotional balancing act largely drives their success in avoiding large protests and the aforementioned unrest tipping point. Figure 7 shows how the Regime blames the GERD, and through use of government messaging, how this affects the population's and the Military Elite's views of the GERD. The graph, 7a, can be interpreted as the relative amount of effort the Regime is putting into blaming one cause versus another for hardships. The graph, 7b, represents what entities are saying about the GERD, where higher than 0.5 means they are saying negative things, and lower than 0.5 means they are saying positive things. Notably, the Islamists respond much faster to the messaging. This is because they are assumed to be a more cohesive group in which opinion can spread more quickly, as opposed to the larger, more diverse general population, and the Military Elite who are less affected by messaging.

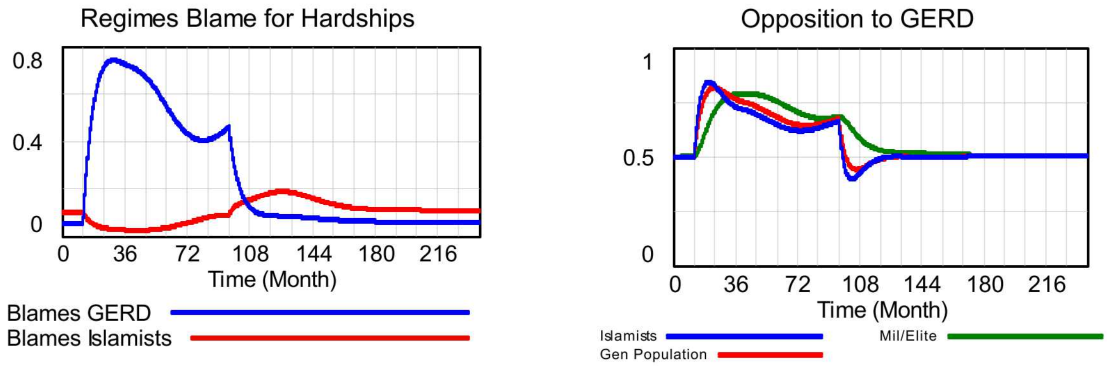

Figure 7. Percentage of propaganda activity by the Regime (left),

and opposition to the GERD by different entities (right).

While the population is worse off and perceives a comparative disadvantage to the Military Elite, their anger toward the GERD offsets much of the dissatisfaction that they would otherwise have toward the Regime. Figure 8a shows the strength of negative opinions by the cognitive entities. Because the subsidies and the opinion against the GERD take time to manifest, negative communications about the Regime increase for the first year of impacts, but are slowly replaced by relatively positive opinions as groups direct their anger toward the GERD. By the fourth year of impacts, as the Regime can no longer afford subsidies, and as dissatisfaction toward the Regime's inaction against the GERD builds, opinion shifts against the Regime. The 'dissatisfaction with inaction' component is shown in Figure 8b. The slight dip around month sixty is because the Regime is taking diplomatic action against the GERD's use, but soon thereafter the population becomes again dissatisfied, as the Regime's actions do not completely eliminate the GERD's effects. A slow decline in market food and energy prices is the result of the Regime's diplomatic action.

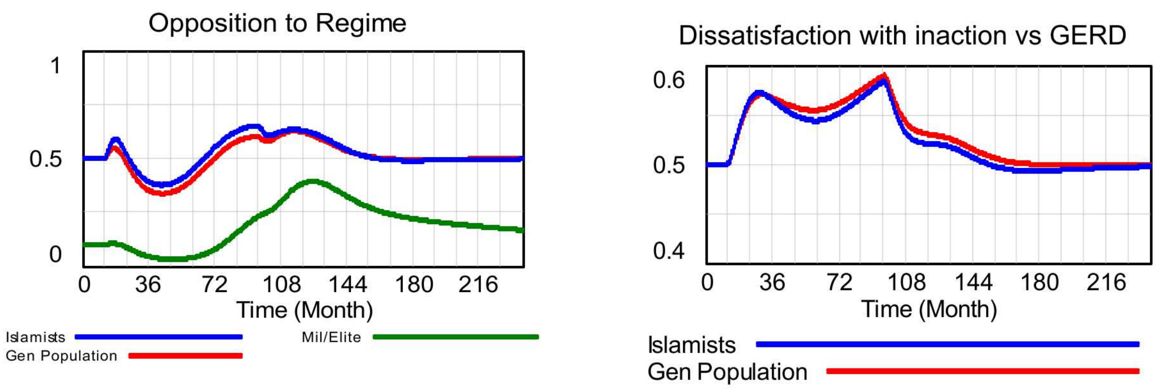

Figure 8. Negative communications directed toward the Regime (left) and dissatisfaction with the Regime's inaction against the GERD (right).

The actual number of protestors in the model is a function of the population's opposition to the Regime and the Regime's ability to suppress and deter unrest. The Regime can suppress and deter more unrest successfully if they have military support. Figure 9a shows the funding that the Regime is funneling to the Military Elite. In the very initial stages of impacts the Regime is trying to increase this funding as an investment in the recovery. As subsidies become too expensive, the Regime chooses to defund the Military Elite programs. This results in the Regime's decay of Military Elite support, as shown by the green curve of Figure 8. This decreasing support is another potential source for an unrest tipping point, but does not become a problem in the base case simulation, where diplomacy is at least marginally effective at decreasing the GERD's impacts.

The amount of unrest declines well after the dam's impacts are over—in fact unrest peaks right as the GERD is almost full. This dynamic is due to the slippage of food and energy subsidies, the resulting decrease in discretionary income for the public, and the use of suppression by the government during the upswing in protests. All of this serves to show that unrest can be a heavily lagging indicator of actual problems, and that the Regime's balance between sentiment management and funding decisions is critical to understand when assessing an external shock such as the GERD.

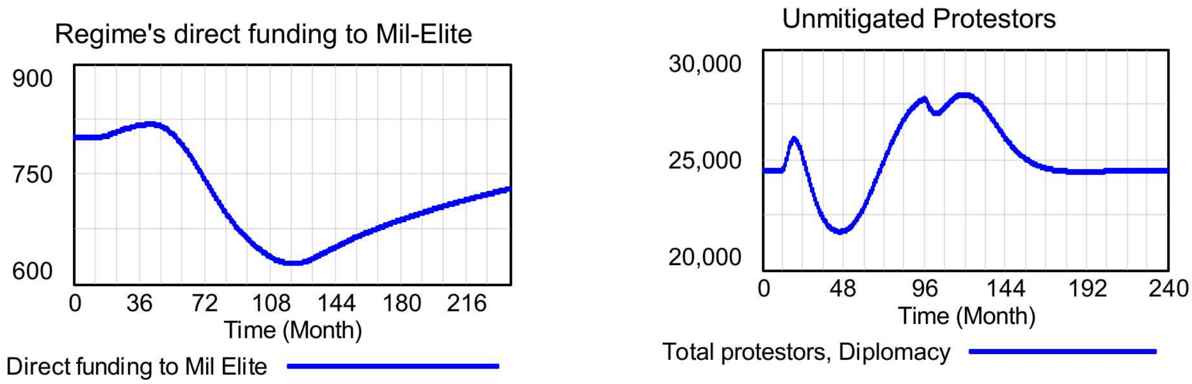

Figure 9. The funding of Military and Elite programs (left) and the number of actual protestors (right). Defunding of the Military Elite could lead to their refusing to support the Regime in their suppression of unrest.

Scenario Conclusions

This example scenario is meant show the relationships that could affect unrest in Egypt between important groups during the period in which the GERD is refilling. Some early insights include:

1. The highest unrest was found well after the GERD’s impacts are over. This counter-intuitive finding is largely due to the long delays in the system. Structurally, unrest is buffered by the Regime’s ability to decrease the economic hardship of the population, and also by its ability to spread propaganda against the GERD.
2. Propaganda against the GERD and food/energy subsides only delay unrest. The best way to prevent unrest is to prevent or mitigate the GERD’s impacts. Effective diplomacy is one strategy that was found to prevent extreme unrest in the model.
3. External shocks to food prices (not related to the GERD) would have a significant effect on popular support for the regime. A price shock occurring before the GERD filling period has potential to be more disruptive than a price shock after this period.

Applying DYMATICA to the Megacities Narrative

In addressing the fictional Megacities narrative, the DYMATICA approach could be applied to lend insight to questions, such as:

1. How might unrest within Xanadu progress and who would it be directed toward given the interactions between the different immigrant/non-immigrant populations?
2. How do different Xanadu economic policies and factors such as the rise in crime and lack of jobs affect the population's response to the immigrant population?
3. How do Xanadu non-economic policies toward immigrant populations affect unrest and influence how Xanadu population will respond the immigrant population over the next 10 years?

Entities and Decisions

A DYMATICA model would simulate system interactions relevant to the questions of interest. The model would incorporate behavioral tendencies associated with the relevant cultures, including differences in belief structures, attitudes, norms, motivations, and intensity of expressed emotions. A macro-level systems model would first be developed to represent the societal-level interactions. At the micro-level, where decision-making would be represented, potential entities could include:

- <u>The Xanadu City Govt.</u>: Assumed to be comprised of former military individuals, the government is primarily interested in improving the Xanadu economy, decreasing the perception of instability by internal and external parties, and maintaining power.
- <u>The Bursuka Refugee Population:</u> Assumed to be comprised of disparate, poor individuals from a different cultural and ethnic background than the Xanadu population.
- <u>The Razinia Migrant Population:</u> Assumed to be comprised of disparate, poor individuals from a different cultural and ethnic background than the Xanadu population.
- <u>The General Xanadu Population</u>: The general population is quite poor by Western standards. Beliefs include a high sense of former pride and the belief that Xanadu remains a leading city.

By determining the relationships between the entities, a list of potential behaviors, motivations for these behaviors, and cues that would activate these motivations would be generated (see Figure 10 as an example).

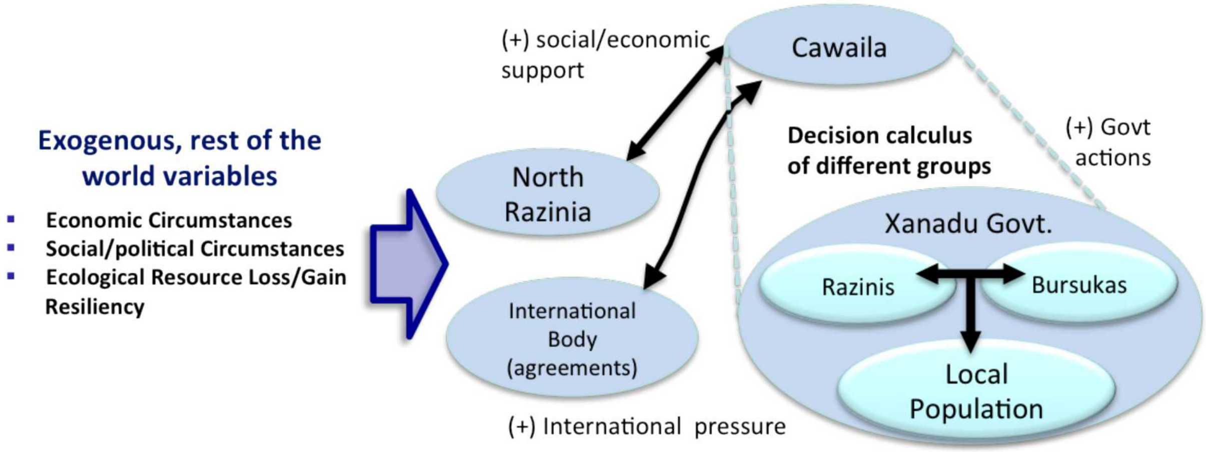

Figure 10. Example of a simplified DYMATICA model

Potential System Behavior: Over-extension of Government Resources. Within DYMATICA models, exogenous variables can be used to stimulate the model. For example, the influx of large populations within Xanadu would heavily strain the Xanadu resources. This includes housing, policing, and medical resources (to name a few). Each variable would need to be included in the model, which could be adjusted to assess how increasing or decreasing each resource would affect stability within Xanadu over time.

Potential System Behavior: Sociocultural Conflict. Another potential behavior of interest is the interaction between the Bursuka refugees, Razinia migrants, the general Xanadu population, and the Xanadu city government. Potential conflict between the Bursukas and Razinis for resources, as well as segments of the Xanadu population would be high. Each population’s sociocultural characteristics would need to be modeled, including how each population interacts with each other. What is important is each population’s perceived plight relative to others. Local unemployment, crime, political influence can have a strong effect on the perceived status and wellbeing of each population. Adjusting these variables to assess the potential impact on the overall Xanadu society, over time, could provide important insight regarding how the government should prioritize its resources. The insights from this assessment could provide a discussion forum detailing relationships responsible for unrest within Xanadu—and could ultimately help explore the policy options required to lower future unrest.

General Conclusions

The DYMATICA framework is based on principles that can encompass a large number of entities with any number of alternative decisions, and with any level of interrelationship complexity. Because of these characteristics, DYMATICA is well suited to examining questions relating to how world model (system-level) variables and/or interventions affect the aggregate expression of individual or group behavioral outcomes. There are many potential use cases for this approach, to name but a few:

- Estimating the potential effects of proposed interventions (including unintended consequences) that seek to alter behavior by affecting the cognitive domain (e.g., information operations, deterrence scenarios, proposed engagement options to arrest or avoid conflict escalation) before they are executed.
- Modeling latent instability within a society (or group of societies) by modeling tensions between groups (in terms of their beliefs and behaviors) and simulating to understand what types of "trigger events" could ignite conflict.
- Definition of the temporal sequence and timing of steps in more complex interventions to achieve the highest likelihood of success (however that is defined).
- Exploration regarding what sets of system-level scenarios might lead to virtuous or vicious cycles (situations in which behaviors create positive [vicious] or negative [virtuous] feedback into the system and cause or prevent behaviors of the same type).

All of this becomes especially useful in light of the realization that "hybrid warfare" has returned to prominence following Russia's recent annexation of Crimea. Indeed, joint military doctrine is evolving as of this writing to embrace the Human Aspects of Military Operations (HAMO), which "describes how the Joint Force identifies, understands, anticipates, and influences relevant individuals, groups, and populations" (HAMO Working Group, 2015, p. 3). As the U.S. military comes to grips with these challenges and begins to build them into its training and doctrine, this type of modeling and simulation becomes more obviously and immediately impactful, particularly when "operations will frequently depend on the application of unique capabilities to identify relevant actors in the environment and influence their decision-making and behavior in a manner consistent with the desired state" (ibid.).

Key Questions

1. What are the differences between system dynamics and agent-based models?
2. How could hybrid computational models potentially increase the utility of sociocultural assessments?
3. What are the macro- and micro-level decision theories represented within DYMATICA?
4. Generally, how does DYMATICA represent decision making and behavior?

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