In BERNARD, M. L. (2020). Using Computational Geopolitical/Sociocultural Modelling to Assess Response Options to Information-Related Hybrid Threats. *Senior Leadership Roundtable on Military and Defence Aspects of Border Security in South East Europe*

Using Computational Geopolitical/Sociocultural Modelling to Assess Response Options to Information-Related Hybrid Threats

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Abstract. This paper describes current and potential future work to support the assessment of societal and governmental responses to various hybrid threats using the modeling and simulation tool DYMATICA. The intent of DYMATICA is to minimize the likelihood of decisions that lead to undesirable consequences by providing a more systematic analysis of group and individual decisions within state and non-state entities. Its focus is on the assessment of higher-order (cascading) influences and reactions to events and conditions.

Keywords. Hybrid Threats, Hybrid Warfare, Nonlinear Warfare, Full Spectrum Warfare, Information Operations, Geopolitical modeling, Sociocultural modeling, Operations Other Than War, DYMATICA

1. Introduction

The past 20 years have seen a dramatic rise in the ability of both state and non-state actors to bypass the powers of a government to directly influence that government's citizens for its own end. While this type of effort is certainly not new, the sheer scale, speed, and intensity is a new phenomenon that governments are seeking to both better address and exploit [1]. For instance, according to the Chief of the General Staff of the Armed Forces of Russia, General Gerasimov, "the rules of war have cardinally changed… the effectiveness of non-military tools in achieving strategic or political goals in a conflict has exceeded that of weapons" [2]. This greater use of indirect actions as a means to create an effect, such as employing specific actions to influence the attitudes of a foreign society, has been embraced by a number of governments throughout the world [2]. As a result, organizations such as NATO are beginning to develop more robust responses to this phenomenon. Indeed, in 2018 NATO leaders agreed to create counter-hybrid support teams to address this threat by providing specific assistance to NATO members in responding to these types of threats [1].

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[2] Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525. This document is approved for unconditional, unlimited release: SAND2020-3318 O.

2. Gray Zone Conditions and Hybrid Conflicts

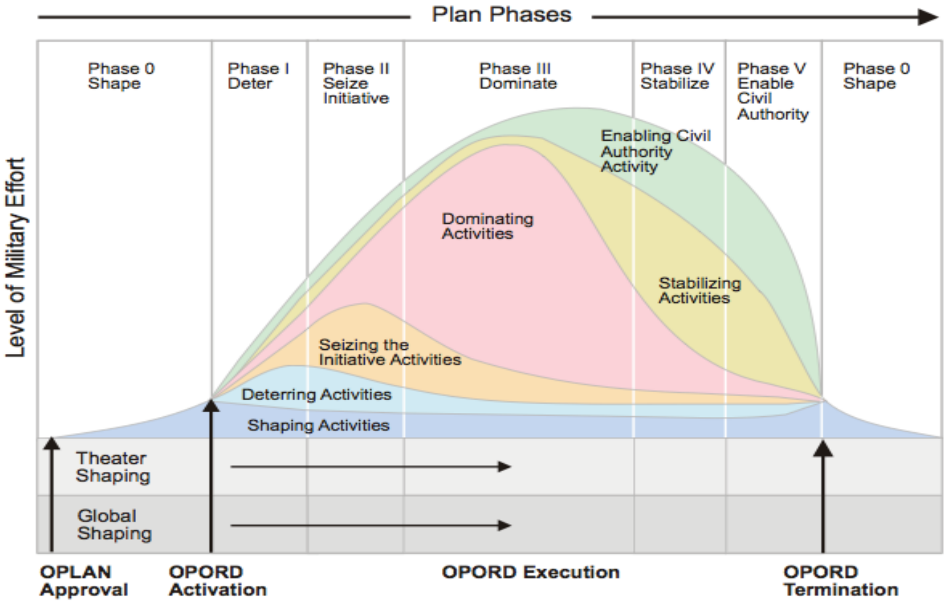

Figure 1. Military phases of military operations. Source: JP 3-0, Joint Operations

A paradigm for military operations used by the U.S. and other militaries follows a six-phase planning and execution construct. This construct consists of a phase 0 (shape), phase I (deter), phase II (seize initiative), phase III (dominate), phase IV (stabilize), and a phase V (enable civil authority) engagement. Within this paradigm different types of activities are performed, starting with an operations plan (OPLAN), leading to an operations order (OPORD), and later to its execution [3]. Ultimately, it is expected this process will lead to the termination of a conflict (see Figure 1). However, a linear phase progression such as this often does not occur. Also, most of the effort underlying an initiative might be directed towards work in a particular phase, such as phase 0, with the intent to prevent conditions that would warrant the need to move to another phase.

Unfortunately, less effort has been placed on understanding and anticipating conditions within the gray areas between phases 0 to III. For example, the Chairman of the Joint Chiefs, General Joseph Dunford stated:

> Our traditional approach is either we're at peace or at conflict. And I think that's insufficient to deal with the actors that actually seek to advance their interests while avoiding our strengths. And as an aside, you know, I don't find the current phasing construct for operational plans particularly useful right now. If you think about it, we bend authorities and capabilities according to where we think we are in a phase. And our adversaries, or potential adversaries, or our competitors… they don't actually find themselves limited by that same – by that same framework.

> And just as an example … we gathered all the combatant commanders together last fall. We said: Hey, in your area of responsibility, what phase is your adversary in? … and consistently the combatant commanders said: Well, I think our adversary is in phase 2, or our adversary is in phase 2½.
>
> And what that means is the actions that they are taking on a day-to-day basis, whether it be in what's been described as the "gray space" – I call it competition with a military dimension short of a phase 3 or traditional conflict, but the activities that they're taking with regard to employment of cyber, unconventional capabilities, space capabilities, information operations are absolutely not associated with what we would call phase zero shaping [4].

This gray area (or gray zone, as it is more commonly called) below phase III conditions is typically associated with actions that are the most difficult to anticipate and to counter. Moreover, while the use of non-military means to achieve military and political ends is as old as civilization, it has been recognized that new technologies along with new tactics, techniques, and procedures (TTPs) have enabled greater use of deception, infiltration, and denial. As U.S. Deputy Secretary of Defense Robert Work stated, these TTPs are "very hard to detect, operating in what some people have called 'the gray zone.' Now, that's the zone in which our ground forces have not traditionally had to operate, but one in which they must now become more proficient" [5].

A gray zone conflict might be carried out between two governments over a weaker government to fulfill some larger strategic interest. Gray zone conflicts consist of an "activity that is coercive and aggressive in nature, but that is deliberately designed to remain below the threshold of conventional military conflict and open interstate war" [6]. The multi-domain military and non-military strategies associated with these types of activities is often termed, "hybrid warfare." Other terms for this concept include full spectrum warfare and military operations other than war [7]. A common example of engagements occurring within this gray zone environment are seen in proxy conflicts. A proxy conflict can provide a means for countries to challenge each other without engaging in direct confrontation. In this type of conflict countries might compete for influence by supporting opposing sides in a political or social conflict. While proxy conflicts have been fought throughout history, the cold war struggles between NATO and the Warsaw Pack have produced many examples of this type of competition. Here, sides might compete for hegemony over some area without risking a direct— potentially nuclear—confrontation between countries [8]. This type of confrontation typically involves three types of country actors: a revisionist, a status quo, and a victim actor.

A revisionist actor might use actions to carry out certain goals by changing the political environment within a less powerful victim actor, but not to the extent that it draws a direct military confrontation from any actor invested in the status quo of that country. The revisionist actor's desire to revise the current order will influence its decision to conduct gray zone activities within a victim actor, such as taking actions to promote political instability. This can take the form of engaging in information operations designed to make the revisionist actor more popular within the victim-actor society or decrease the ability of the victim-actor to resist the influence of the revisionist actor. This can be moderated by a status quo actor's resistance to these gray zone activities, which can increase the perceived cost of a gray zone conflict. A status quo actor will seek to keep the current power structure as is—often to the point that it is willing to take military action to keep this status quo in effect. This relationship is shown in Figure 2. Domestic factors, such as reduced leadership popularity (often creating a desire to deflect attention from domestic conditions) could cause actors in both circumstances to be drawn to increase pressure to either intensify revisionist or status-quo activities [9, 10]. This, in turn, can cause both types of actors to increase their activities, potentially leading to a more conventional war.

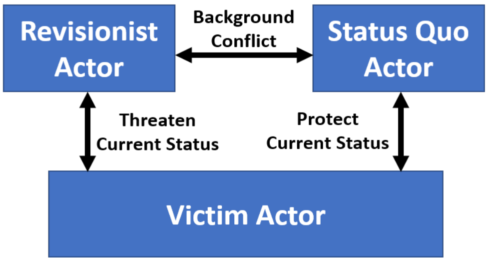

Figure 2: Actors and interactions

3. DYMATICA and Gray Zone Activity Assessments

A common problem associated with the effort to better assess the occurrence and effect of activities below the threshold of war being instigated by one or more actors is the shear difficulty in comprehending the dynamic nature of societal systems, particularly over time and considering feedback effects. To help address this problem, Sandia National Laboratories (SNL) is using a computational modeling and simulation approach to help decision makers better understand and anticipate the decision calculus of populations and government within societal systems. The intent is to minimize the likelihood of decisions that lead to undesirable consequences by providing a more systematic analysis of decisions within state and non-state entities. DYMATICA (DYnamic Multi-scale Assessment Tool for Integrated Cognitive-behavioral Actions) simulates the dynamic psychosocial, geopolitical, and socioeconomic interactions within and between actors. The decision-making of actors is represented within socio-cognitive models that are embedded within a larger simulation framework.

DYMATICA is designed to support existing assessment methods by providing greater insight into interactions and influences that can affect the outcome of a situation. With this, DYMATICA assessments are intended to inform rather than predict precise behaviors by focusing on likely dynamic repercussions of actions—which could help to better understand and compare likely effects of potential courses of action (COA) or actions of other entities under a variety of scenarios[3]. For example, DYMATICA has

[3] The DYMATICA effort began in earnest in 2008 and has grown to include a number of technically diverse assessments. Since 2008, approximately 18 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 partners include the United States' Department of Defense, international military partners, the intelligence community, as well as SNL through its internal Laboratory Directed Research and Development program.

been used to support the generation of options regarding how certain populations will likely respond to different policy measures, cyber disruptions, targeted disinformation, and the like, while accounting for uncertainty in the environment. This paper will describe current work being done to extend DYMATICA so that it can be applied to both assessments and military training environments concerning hybrid conflict scenarios.

3 .1 The DYMATICA Framework

The DYMATICA framework was developed by using a system engineering approach to the incorporation and structuring of data-supported behavioral-economic, political, psychological, and sociological set of theories. Computationally, the DYMATICA structure consists of a hybrid, systems-dynamic/agent-based modeling framework. Here, cognitive models represent decision making of individuals within societies, which are embedded within a broader societal, systems-level framework. System dynamics represents interactions and incorporates both endogenous and exogenous system-level components. DYMATICA uses decision theories, data, and subject matter expert (SME) input to construct and parameterize equations using robust statistical regression methods. The theories and structure are expressed using differential equations. The structure allows for an assessment of behaviors across different topic domains and at different scales of human interaction. Each simulated behavior is a function of psychological characteristics, along with environmental and group-dynamic factors. The result is a framework that connects the multiple scales of human behavior (from individual to societal interactions) to the external (geopolitical, physical, and socio-economic) world.

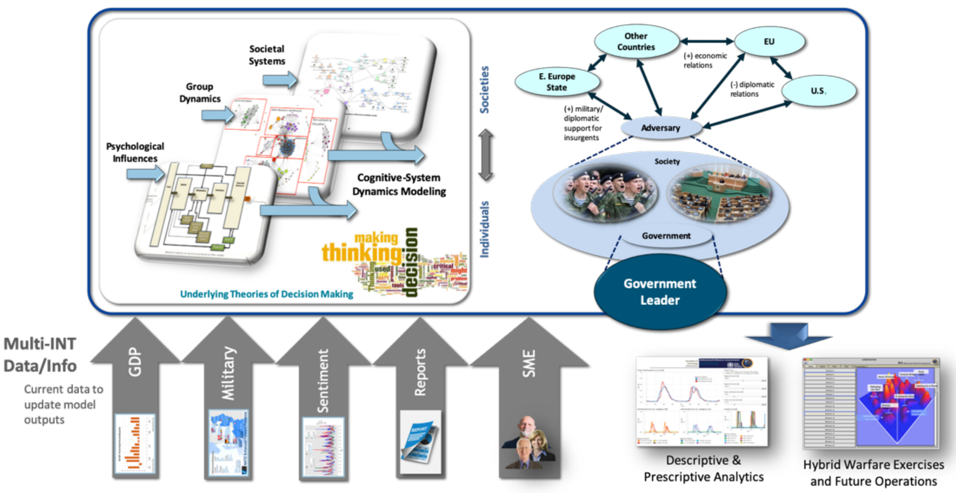

Figure 3. General overview of the DYMATICA process

Figure 3 provides a general overview of process underlying a DYMATICA assessment output. Here, various forms of information can be used to populate a DYMATICA model such as a country's economic wellbeing, its military potential, the sentiment within the country, along with report documents and SME guidance. Typically, reports, data, and

SME guidance provide the information needed to assign weights associated with psychological and sociological elements that inform the decision representation within DYMATICA.

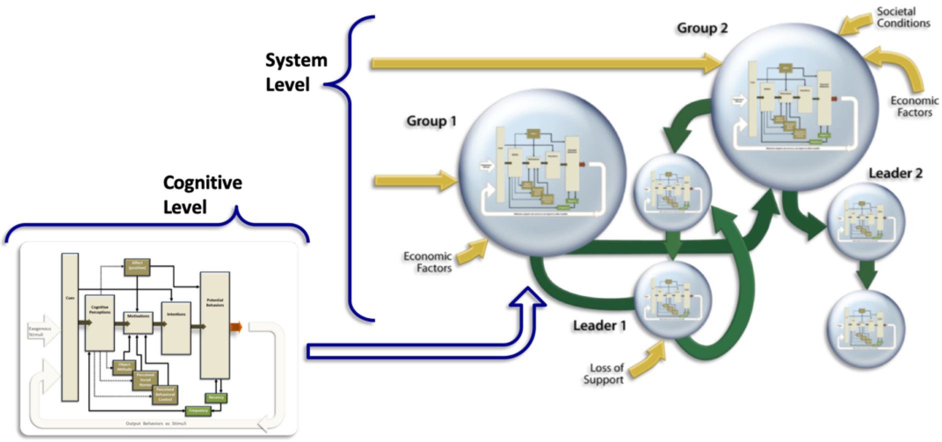

Figure 4. A simplified example of a DYMATICA framework consisting of a systems level and a cognitive level

The process of developing DYMATICA models of societal and country interactions begins with an overarching question. This helps to focus and constrain the model so that only essential elements are represented within it. As an example, figure 4 shows a simplified example of the modeled dynamics within a country, including specific groups, such as political parties as well as leaders. An overarching question might address the internal conditions within a country, along with external pressures, that could cause that country to be politically unstable.

When certain groups, institutions, or individuals have a pronounced effect on the overall system of interest (such as political parties and/or the leader of a country), a cognitive structure within DYMATICA is used to represent the decision making of those entities. The modeled entities process and respond to the system-level information based upon empirically supported theories of decision-making. For example, these entities incorporate psychological and sociological elements within their structure, such as environmental cues, perceptions, motivations, intentions, and behaviors (see Figure 5). The modeled system-level information and behavioral outputs of one entity will serve as cues to other entities, which can, in turn, process that information to produce additional behaviors across time. Thus, across time steps, the modeled entities can respond to actions of other modeled entities as well as to co-occurring environmental cues. Modeled human behavior is determined by local perceptions of world conditions, contained in a feedback process that link behaviors of others, conditions, and events.

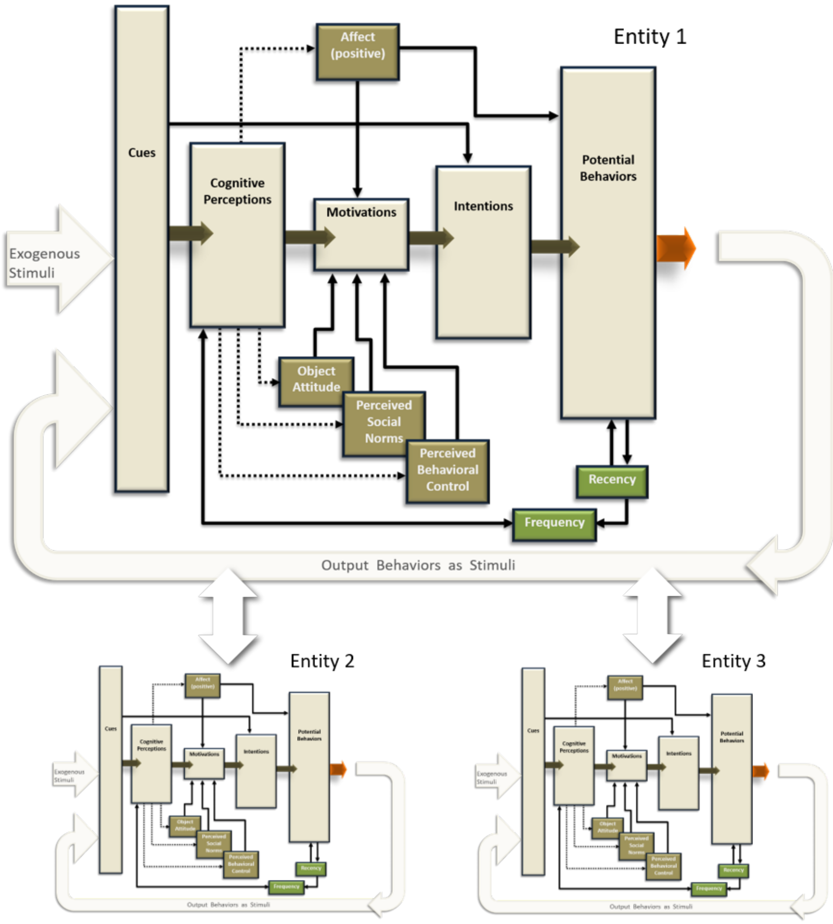

Figure 5. The conceptual structure of the underlying decision-making process within DYMATICA

In addition, the DYMATICA structure is informed by an integrated a set of elements from psychosocial theory that are consistent with economic theory, along with experimental and historical data pertaining to human behavior. DYMATICA uses real observations and data, decision theories, and SME input to help construct and parameterize equations via statistical regression methods, which are expressed using differential equations. The result is a framework that connects the multiple scales of human behavior (from individual to societal interactions) to the external (geopolitical, physical, and socio-economic) world. DYMATICA represents how these entities and conditions unfold over time, with an emphasis on response and counter-response progressions. To computationally instantiate the theories and processes described above within DYMATICA, a mathematical representation was developed to capture these dynamics.

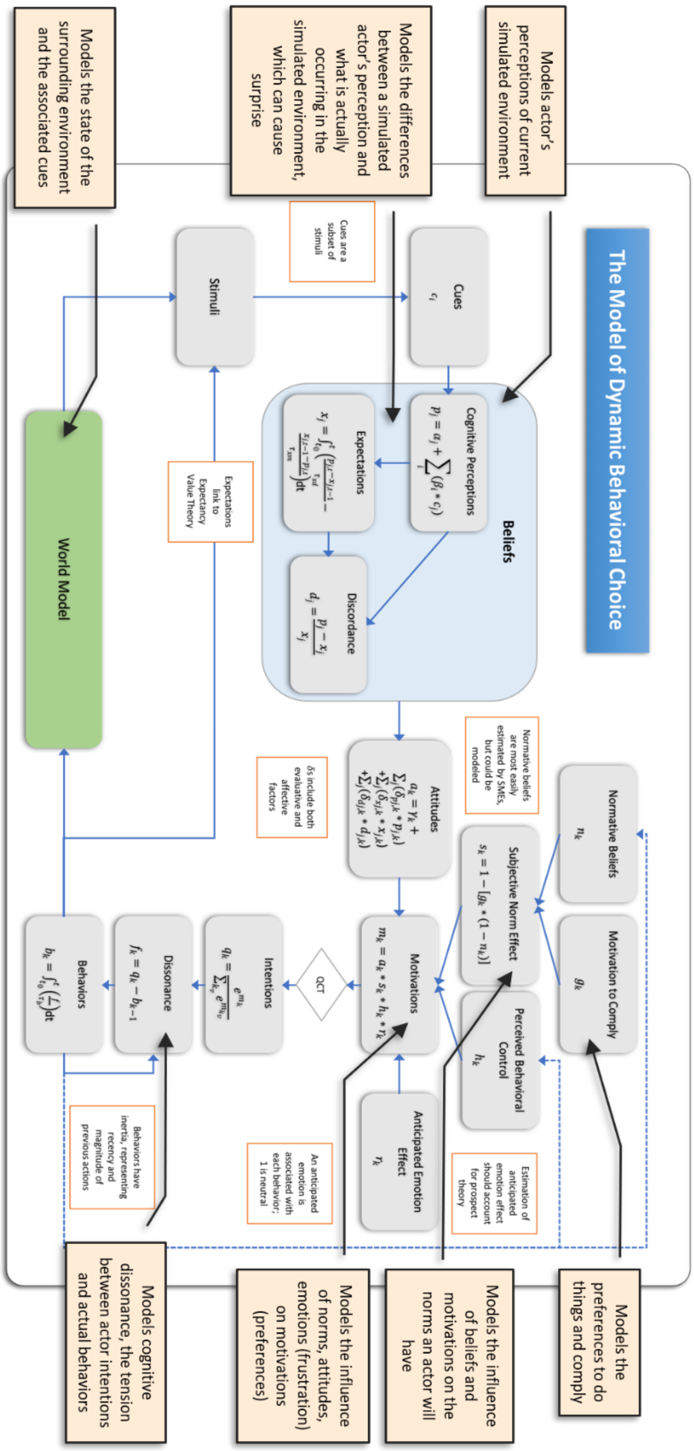

Figure 6. The computational instantiation of DYMATICA

Figure 6 shows the general mathematical structure that is instantiated within DYMATICA. Looking at figure 6 from left to right shows how DYMATICA models how humans generally perceive their environment, process that information, and ultimately act upon this information. The inputs of the cognitive structure are represented as cues that are perceived from the environment. One collection of cues might form a specific perception of a current situation, whereas another collection of cues might form another perception. Here, each environmental cue will have a different weight that provides evidence that a specific perception is active. For some perceptions to be active, multiple cues are needed to be present in order to meet a set threshold. However, for other perceptions, only a few or even one cue might need to be present. It depends on the saliency of each cue and its evidence associated with that perception.

DYMATICA can play out multiple “what if” scenarios where cues are inserted at different times during the scenario. The time horizon associated with a scenario could last as long as several days to ten or more years. The perceptions that are active at any given time can be compared with previous instances, which causes a comparison between an expectation based on prior experiences with the current perception. If there is a difference between the two, a discordance arises. This discordance can cause learning within the model that can be incorporated into subsequent time-step simulations.

An active perception can give rise to one or more motivations to perform some type of behavior. The selection of a particular motivation is a function of the attitude, social norms, and perception of behavioral control associated with that perception. To model these phenomena, data, research, and SME guidance are used to assign corresponding attitude, social norm, and behavioral control weights for each perception. In addition, the corresponding anticipated emotional effect is also assigned a weight for each perception. The motivation that is selected is a function of which perceptions are most active during a given time step.

The motivation that is selected will activate a more specific intention to perform a certain behavior. The behaviors that are selected as the highest probability of being engaged are ones that correspond most closely to the emotional valiance associated with active perceptions. Also affecting the probability of behaviors are their frequency and recency in time. These behavioral outputs will serve as cue inputs to other entities. A more in-depth discussion of this process is discussed by Bernard and colleagues [11].

Various validation techniques are used to determine and improve model accuracy, the efficacy of data inputs on model response, and intervention points with the greatest effect(s) on system results. This process involves the identification and quantification of uncertainties associated with data pertaining to model parameters, SME opinion, and open source data. Here, statistical methods are used to characterize data uncertainties. The formal analysis of the simulation results characterizes model confidence and robustness for what-if queries regarding various policies and actions.

Model confidence management procedures typically incorporate uncertainty quantification (UQ) and sensitivity analysis (SA), as well as other validation techniques. This involves ongoing, collaborative assessment to ensure that the final product provides useful information for the desired application. Uncertainty quantification is also used to learn how uncertainty in inputs ultimately propagates through the model to affect results. By simultaneously performing UQ for model parameters and potential interventions, the framework is able to determine the portfolio of interventions within a range of probabilities of success despite uncertainty. The risk associated with the intervention is also quantified. Once parameter ranges are defined, various options are available for propagating uncertainty throughout a model. This approach not only enables the comparing and contrasting of alternative outcomes, but also reflects the uncertainty that an intervention must accommodate. The resulting assessment output typically portrays how various COAs and conditions jointly affect various endogenous model parameters at the geopolitical level (e.g., country interactions), group level (e.g., political parties, ethnic groups, urban/rural group, etc.) and individual level, such as leaders of countries.

3.2 DYMATICA and Gray Zone Behavioral Assessments

Because the foundation of DYMATICA is based on empirically derived theories of human decision making, it is well positioned to potentially help analysts better anticipate and understand the effects of hybrid conflict behaviors pertaining to populations and governments. As an example, the discussion below provides a description of how DYMATICA is currently being developed to assess societal responses to intentional infrastructure and social disruptions by an external adversary, as well as assessing an adversary's decision calculus to initiate such a disruption.[4]

3.2.1 Application Area: Societal Responses to Hybrid Attacks

Through an effort funded by the U.S. Department of Defense, DYMATICA is being extended to assess the effects of intentional infrastructure disruptions and disinformation designed to negatively affect governmental and societal functioning within a country. For instance, infrastructure attacks might not only seriously disrupt the physical functioning of a country but could also sow panic and confusion within its society. This could lead to a loss of faith in the capabilities of local and national institutions along with exacerbating physical disruptions through hoarding, rioting, and the like. In addition, adversarial disinformation could further this process by causing greater confusion.

Openly published news reports have recently indicated that foreign military intelligence organizations have indeed infiltrated power plant control rooms and have engaged in cyberattacks that target nuclear power plants, water, and electric systems [4]. These types of attacks are seen as a signal that an adversary could disrupt a country's critical facilities in the event of a conflict. For example, countries like Russia and North Korea have been accused of using distributed denial-of-service (DDOS) attacks to shut down telecommunications, such as television stations, the Internet, and other services to create confusion as a prelude to an aggression. This type of activity was seen during Russia's invasion of Georgia in 2008 and in the Ukraine today. It can also be used as a means to punish a nation by creating power outages. This was believed to occur within Ukraine in 2015 and 2016, leaving more than 200,000 citizens without power [12].

3.2.2 Adversary's Decision Calculus to Initiate an Attack

Besides assessing how specific populations and institutions will respond to an attack given various co-occurring conditions, DYMATICA has also assessed how internal and external pressures make it more likely that an adversary will initiate an attack on the infrastructure or societal mechnisims of a country[5]. This could include modeling and assessing such entities as governmental institutions, along with state-supported crime networks and nationalistic communities by examining their behavioral patterns across time and in specific events. While DYMATICA cannot point-predict the timing of specific adversarial behaviors, it can indicate the range of likely behaviors across time and how specific COAs can modify or strengthen their overall shape of behaviors. For example, figure 7 illustrates how a potential intervention can change the shape of an adversary's behaviors across time so that it is more favorable to NATO interests. Even though the exact behavioral path cannot be fully known ahead of time, due random events that take place in the environment, examining the general range of paths should be useful in determining how internal and external pressures will likely affect an adversary's decision to initiate an attack. In this example, each single red line represents a potential behavioral path over time. If the overall shape of behaviors is acceptable then knowing the specific behavioral path that is taken is not as important. However, if there is a bifurcation where most of the paths are acceptable but some or not, then the focus could be on the potential behavioral paths that are not acceptable. This would include the assessment of particular conditions that lead to the undesirable paths and how to reduce the potential for these conditions to occur.

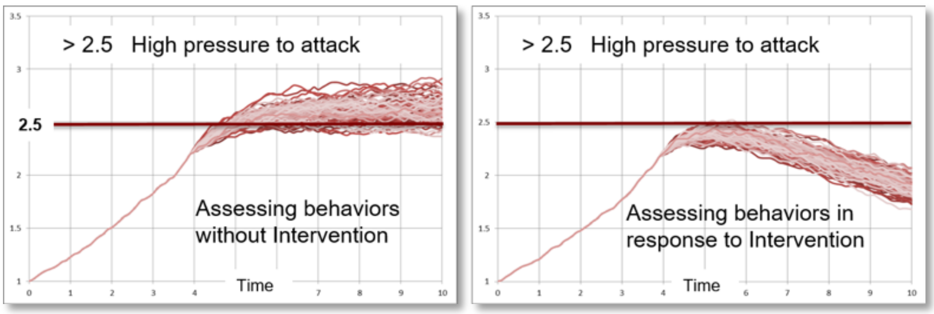

Figure 7. Each red line represents a specific behavioral path across time.

[5] Including targeted propaganda, disinformation/weaponizing of information, and other attacks on the economic, political, and social stability of a country.

4. The DYMATICA System Applied to Gray Zone Activities

Currently DYMATICA can assess how multiple institutions (such as governmental, banking, and media outlets) and groups (such as high, medium, and low socioeconomic populations) within a country would most likely respond to disinformation campaigns and acute infrastructure disruptions that dynamically co-occur within various political, military, economic, social, information, and infrastructure (PMESII) conditions. The U.S. Department of Defense is leveraging this effort to help develop a capability to better assess the intent, objectives, and strategies of adversaries pertaining to a range of infrastructure and societal attacks on a victim-actor country[6].

To accomplish this, DYMATICA is being extended so that it can assess how a combination of socioeconomic, geopolitical, military and environmental conditions, as well as the spreading of information and other societal contagion effects, affect the propensity for an adversary to attack. Also being developed is the ability to assess the resilience of that population and governmental institutions to these attacks. This is being done by coupling DYMATICA to a social media model to represent social metadata information and with detailed infrastructure network models to accurately simulate disruptions within a victim country's infrastructure[7]. While still in mid-development phases, this work is producing an initial simulation that addresses how disruptions in such things as electrical power (including Internet communications), foodstuff, petroleum/natural gas, and commuter/ freight rail services affect various populations. To accomplish this, a semi-fictitious city was developed in order to meet specific training tasks and to keep the scenario at a non-sensitive level. Modeled adversary behaviors are based on actual, but non-attributed behaviors.

For this effort, the semi-fictitious city was created based on actual data from typical cities of the same population density of approximately 500,000 to 750,000 people. Behavioral information related to the size of the population, ethnic diversity, urban density mix, and existing infrastructure proficiency was gathered from existing European city data. This included within the models the typical prevalence of roads, including their general condition, as well as the typical number of grocery stores, restaurants, gas stations, hospitals, police, fire departments, places of worship, schools, and rail/subways. Figure 8 shows the modeling of electrical power lines within the modeled city. The modeling of power included the distribution of power along the lines, the generator power, and its load within each unit, which as roughly equivalent to a city block.

[6] This work is being done under a larger effort being led by principal investigator Andjelka (Angie) Kelic, PhD. at Sandia National Laboratories.

[7] This work is leveraging capabilities developed under the National Infrastructure Simulation and Analysis Center (NISAC) program, located at Sandia National Laboratories.

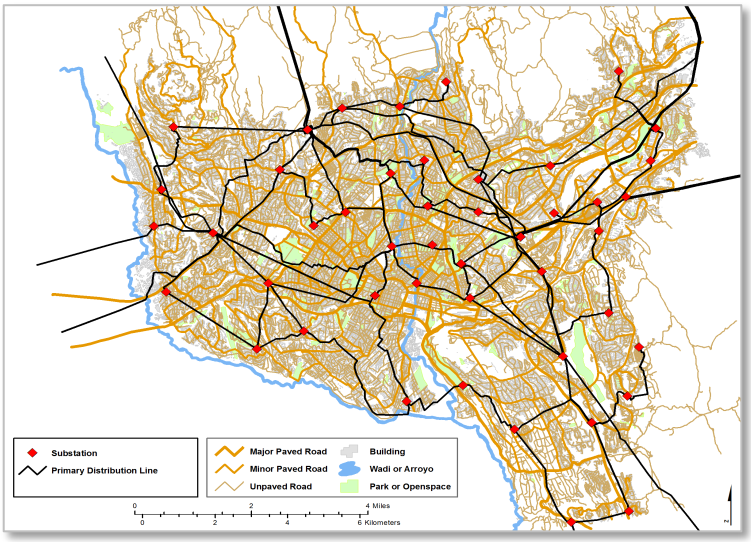

Figure 8: Modeled electrical power within a semi-fictitious city

The modeling of fuel distribution (Figure 9) included the availability of fuel at the gas stations, the usage of fuel by buses and other vehicles, and the fuel use by households and stores. The modeling of transportation (Figure 10), included the type of routes, the disruption of routes, along with vehicle loads (potentially causing congestion and delays), and bus usage. In addition, a social media model was coupled to DYMATICA that produced a typical type and magnitude of social media reaction (such as through Twitter™) in response to infrastructure disruption event, including the length of the event.

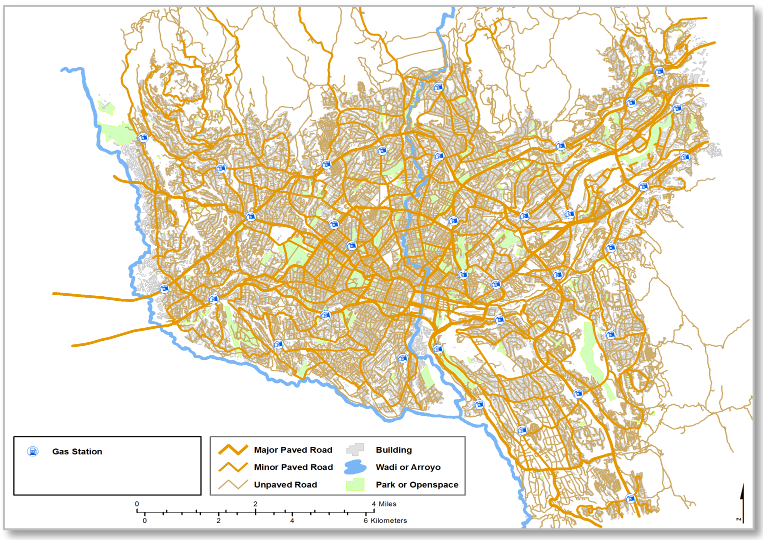

Figure 9: Modeled gas stations (blue dots) within a semi-fictitious city

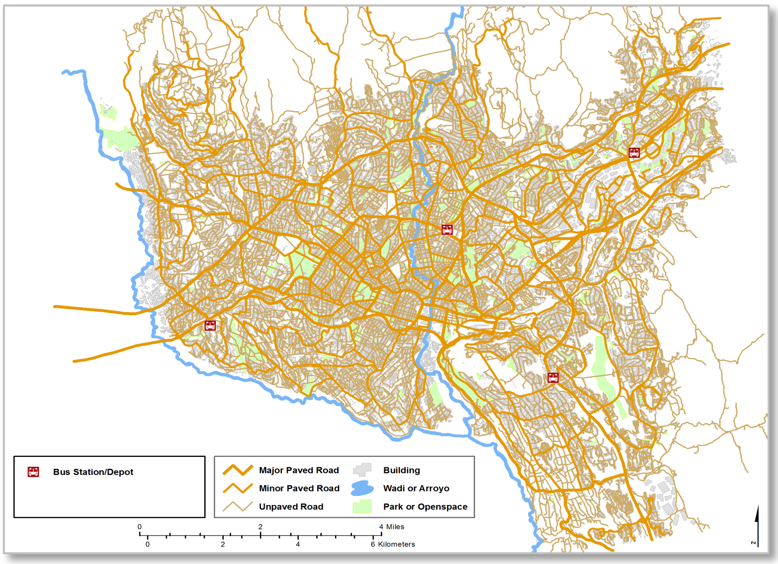

Figure 10: Modeled transportation system within a semi-fictitious city

Coupled with the above-described models, DYMATICA was used to create an initial simulation of how specific adversary institutions, groups, and populations could work together to target a victim country across a spectrum of hybrid warfare activities. In addition, DYMATICA models are being used to simulate major institutions that would be involved in planning and perpetrating attacks, as well as behaviors of government affiliated and non-government affiliated groups that typically help carry out these types of attacks (such as "patriotic" hacker groups, nationalistic Internet trolls, crime organizations, and the like). The full hybrid warfare assessment system that is being developed is described below.

4.1 Work to Develop a Hybrid Warfare Assessment and Training System

To have a system that reflects societal responses to hybrid warfare activities within this gray zone environment requires the coupling of multiple types of models and techniques. Figure 11 shows how DYMATICA is being coupled with infrastructure and social media models to develop a hybrid warfare assessment and training (HYWAAT) system. In this example, three DYMATICA models are coupled with different types of infrastructure models and an agent-based model. When completed, the DYMATICA models will represent a vulnerable society, including its major institutions and populations (i.e., a victim actor), a country that is supportive to the victim country (i.e., a status-quo actor), including its major institutions and populations, as well as an aggressor country (i.e., a revisionist actor). Within the vulnerable society DYMATICA represents decision making of governmental, banking and media institutions. It also can represent high, medium, and low socio-economic status populations (SES; represented as groups A, B and C in the Figure). This could also include minority groups and their relationships with other minority groups, as well as the majority group and the institutions within that society. Also included in the form of adjustable parameters, are economic conditions, military capabilities, and general resources of the modeled country. This is being developed by having a model that represents the decision elements (i.e., perceptions, motivations, intentions, behaviors and the like) for each group and institution entity within each actor. Cue-related information is common to all modeled group and institution entities where each entity will perceive and respond according to their modeled decision calculus, such as their perceptions and motivations.

Modeling the decision calculus of each entity comprises of capturing and representing key decision elements pertinent to those entities and the scenario. These are derived from reports and data with respect to a modeled entity's perceptions, motivations, norms, and behavioral intentions associated with the scenario[8]. This information is structured in a manner that characterizes both the shorter-term (six hours) and longer-term (such as one or more years) decision processes of institutions and populations. For example, in examining populations, short-term behaviors would be most relevant in responding to infrastructure disruptions. However, governmental institutions would need to respond to both short-term and longer-term disruptions, which would necessitate longer-term goals and policies to remedy the disruptions.

[8] Scenario stories consist of detailed interactions between entities to address situations such as an adversary's desire to socially, militarily, and/or economically destabilize and reduce confidence in a victim government in order to create change in behavior that is favorable to the adversary state.

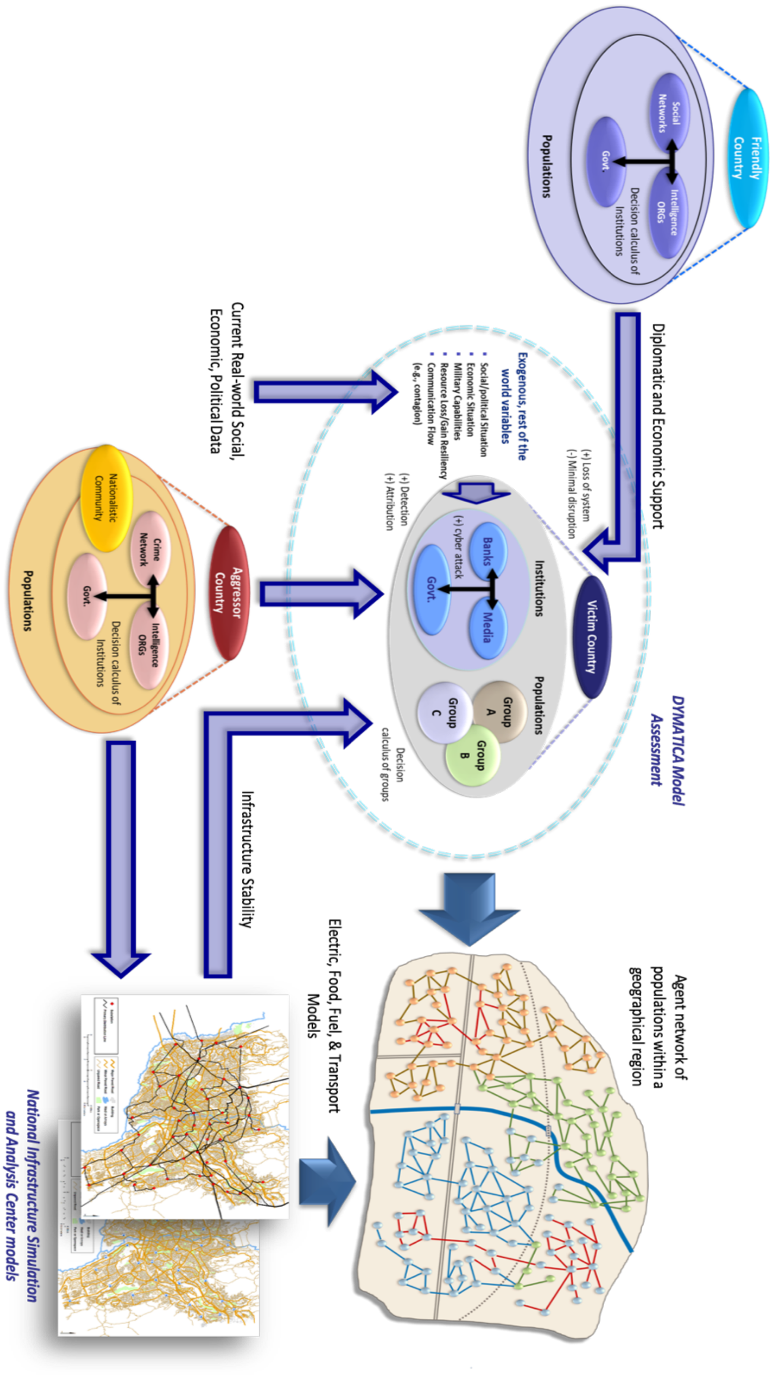

Figure 11. DYMATICA is being coupled with other modeling tools to better assess institution and population response to infrastructure attacks.

As each entity receives information it will process that information according to its modeled decision structure. The DYMATICA output, in the form of behavioral intentions for each type of entity (and for each time step), will be conveyed to an agent-based model that represent multiple instantiations of that entity via an agent-based network. This enables the system to represent multiple, agent-level instantiations of a DYMATICA entity so that smaller units (such as households) can be represented. The agent-based network is able to interact with itself and directly with the simulated physical environment (for instance, a low socioeconomic status entity could be represented by many interacting agents (to represent the behaviors of a household) situated in various areas within a larger geographical region). To illustrate, let's say that group "A" within a DYMATICA model represents a high SES group. The decision-making characteristics of that entity would inform the associated agents within the agent network to reflect those characteristics, but still respond to local surroundings. Group "B" might represent a low SES group and would have the different characteristics (due to more constrained resources), which would inform the associated agents within the agent network to reflect those characteristics, but also respond to local surroundings. Because interactions at this level are represented within an agent network, contagion effects can also be assessed such as the spread of information or emotional sentiment. In these simulations each agent would be affected by local conditions within that area—such as geographical constraints, specific infrastructure or environmental disruptions, and group affiliation. For example, a low SES agent would respond differently to a disruptive infrastructure event in the same geographical region than a high SES agent. It also might be that a high SES agent might be located in a modeled geographical region that has fewer infrastructure problems along with greater resources to deal with infrastructure problems as they arise.

For populations, shorter-term (day-to-day) decision-making considerations will be explicitly represented. For governmental and business organizations, both shorter-term and longer-term decision-making considerations will be explicitly represented. The modeling of longer-term goals for these types of organizations is meant to represent strategic-level thinking that take place over longer periods of time. Parameters could be adjusted to represent specific infrastructure disruptions. The perceivable disruptions will both serve as cues inputs for the DYMATICA model as well as potentially alter local behavior of the individual agents.

4.2 Work Being Done to Develop a Hybrid Warfare Training System

While historically DYMATICA has been used for prescriptive and descriptive analytics, its potential value has also been recognized as an explicit, training exercise tool to help organizations such as NATO better recognize, understand, and train for adversarial hybrid warfare attacks. Here, the system described above could address actual (on-going) or potential hybrid conflict scenarios of interest. This would be done through the creation of a training "script" outlining daily events and conditions of interest that would occur in half-day increments for some simulated time, such as a year. The script would include both scenario-relevant information, scenario-irrelevant information (as distractors and noise) and would provide cues for the DYMATICA models. For example, on day 34 at night the scenario might have a scenario-irrelevant event such as a powerful rain and windstorm that damages much of a simulated city. This would provide information to the DYMATICA entities, as cues, that this event occurred. It would also provide information to other models, such as the power infrastructure model, that 1/3 of a modeled city has lost power. It could also cause the social media model to produce social media regarding this event. If the loss of power continues over several days across the city, then other infrastructure models, such as a food model, could produce a reduction in the availability of foodstuff. This could cause the social media model to increase the volume and intensity of the text messages about the disruptions. On day 35 in the morning a hybrid conflict event might occur. This event could be a targeted attack on the electrical grid within the city, causing another 1/3 of the modeled city to lose power. This might cause the modeled entities to respond in a more negative manner against the local government. All of the behaviors of the modeled entities would be based on actual behaviors that have occurred in the past within similar circumstances and environments.

The degree of subtility of the hybrid attacks can be adjusted to be very difficult to detect from random and natural events to being easily detected. The actual output of the subsequent modeled and scripted behaviors would be expressed through several different means. In this example, the outputs come from societal behaviors such as greater hording of food and gas, greater traffic congestion, generated surveys on public sentiment, social media (topics, number of messages, and level of reactions), new media reports, and generated (simulated) intelligence reports describing activities which provide information pertaining to events of interest. From this information, analysts can attempt to piece together disparate information to attempt to make sense of the events that are co-occurring with random events that are occurring in the simulation.

4.3 Work Being Done to Continuously Update and Calibrate the Models.

To continuously update and calibrate DYMATICA with changing conditions of the real world, new data is needed to be ingested and incorporated within the system as it is made available. This includes such things as polling, economic, and infrastructure data along with social media information, such as Twitter™ feeds. Current work is being done to enable social media and other forms of data to be ingested within the DYMATICA structure via a SNL-developed intelligent web crawler, Avondale™, to perform intelligent crawl of the web and other data sources for documents of interest (i.e., topically relevant to a target document of interest) and to synthesize large amounts of information using text analytic techniques. Key websites can be regularly visited, and their data can be captured for automatic input to update DYMATICA (for example, current GDP of relevant countries, price of oil, and similar data points). Ingesting real-time, relevant data into DYMATICA is considered to be a longer-term effort due to its complexity.

4.4 Potential Application of DYMATICA for Training Exercises

According to Eurasian expert Keir Giles, "NATO forces should by now be training and exercising with the assumption that they will be under not only electronic and cyberattack, but also individual and personalized information attack" [12]. To that point, a NATO online publication stated that, "training, exercises and education play a significant role in preparing to counter hybrid threats. This includes exercising of decision–making processes and joint military and non-military responses in cooperation with other actors" [1]. Currently, the use of training exercises and education specific to hybrid threats is still underdeveloped. Thus, the continued development of a system as described above could potentially be of value. This type of system could be embedded within a larger training exercise to complement traditional exercises that focus mainly on phase III to phase IV military operations. For example, a training system of this sort could focus on phase 0 through II, beginning before the more conventional phase III conflict training exercise would start. This training could continue to complement the existing training exercises throughout the simulated phase of conflict. This training could focus on concerns such as infrastructure disruptions, disinformation campaigns, economic warfare, and the like for a particular population and government. In addition, real-time social media information from specific countries could be used to inform the DYMATICA models on current attitudes and sentiment associated with topics of interest.

Ultimately, the intent of this work is to produce a HYWAAT exercise support system that can, in real time, inform and help anticipate and counter adversarial hybrid warfare behaviors. The intent is to also provide the information needed to help societies become more resilient against these type of attacks (see Figure 12). While work is being done to develop the HYWAAT capability, it should currently be considered as only in its initial, developmental stages. Modeling and assessing the conditions and actions underlying this type of environment is highly complex and will require more basic research and development.

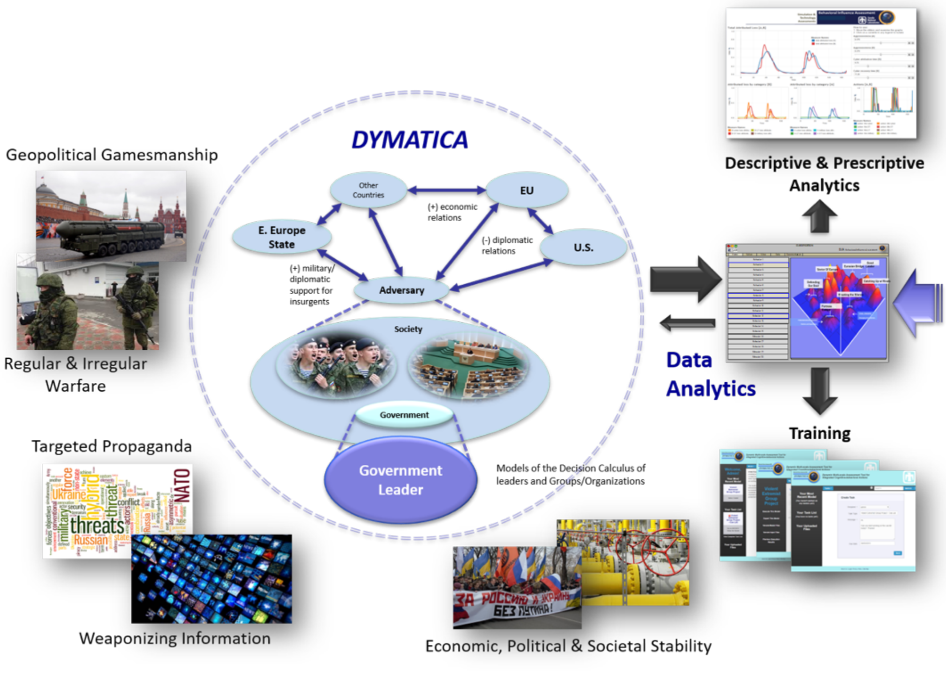

Figure 12. DYMATICA is being developed to address both hybrid conflict assessments and training.

4.5 Application of DYMATICA to Assess Societal Responses to Disasters

In addition to directly assessing hybrid threats, DYMATICA can also assess the effects of natural (physical and non-physical [such as influenza pandemics]) and man-made environmental disasters on societies and how these events can destabilize a country. This type of work can be done in concert with assessments that examine opportunistic hybrid attacks by a NATO adversary. Previous assessments of this type were achieved by coordinating with the National Infrastructure Simulation and Analysis Center (NISAC). NISAC was established from funding through the US Department of Homeland Security and by a US Department of Energy National Laboratory Team comprising of Sandia National Laboratories, Los Alamos National Laboratory and Pacific Northwest National Laboratory. This center has deep experience in modeling and assessing natural and man-made disasters, such as floods, hurricanes, and migration movements. Coupling DYMATICA with these types of models has enabled analysts to explore links among social, economic, human resilience, and ecological conditions, including conflict. For example, DYMATICA coupled with hydrology, agriculture, and economic models assessed how impacts derived from development initiatives in one sector (e.g., water management) might propagate outward to affect other sectors, triggering development and security concerns across a region [16].

An important aspect of this combined infrastructure societal-reaction framework is its ability to concurrently assess short-term (hours to days) and longer-term (several years to decades) behaviors. This can enable more precise and robust analysis of how different populations and governmental and business organizations, residing within different geographical regions, differently respond to disaster events within a day and over longer periods of time. Furthermore, as conditions change data associated with the changed conditions can update DYMATICA so it could be calibrated with the more current information. In performing assessments, analysts are able to adjust different parameters (such as the type and degree of disruptions and the type and timing of responses) to help determine the most effective responses for different communities, geographical regions, and conditions. The DYMATICA assessments could then be graphically displayed in commonly available and sharable visualization platforms.

4.6 Work Needed to Produce the Environmental Disaster, Societal-Reaction Framework

To perform the type of assessments described above, DYMATICA could be coupled with social media models that simulate social contagion and disinformation campaigns, environmental models (such as hydrology, agriculture, and weather models), and infrastructure models (such as electrical, oil and gas, transportation, and communication network models). The environmental disaster, societal-reaction (EDSR) framework would model the decision calculus and interactions between various population, group, and organization entities. Modeling the decision calculus of each entity would comprise of capturing and representing key decision elements pertinent to those entities and the scenario. These would be derived from reports, data, and SME knowledge with respect to a modeled entity's perceptions, motivations, norms, and behavioral intentions associated with the scenario. The DYMATICA output, in the form of behavioral intentions for each entity (and for each time step) would then be represented by multiple instantiations of that entity (for instance, a low socioeconomic status entity could be represented by thousands of interacting agents situated in various areas within a larger geographical region). Each instantiation could be affected by local conditions, such as geographical constraints, infrastructure or environmental disruptions, and group affiliation. For populations, shorter-term (day-to-day) decision-making considerations would be explicitly represented. For governmental and business organizations, both shorter-term and longer-term decision-making considerations would be represented.

5. Conclusion

This paper discussed the history, pedigree, along with potential applications of the current DYMATICA capability and how it is now being extended to assess the dynamics associated with societal and governmental responses to hybrid conflict situations. This current research and development work is focusing on descriptive and proscriptive assessments and as a means to ultimately support training exercises within this domain. While much progress has been made, more work needs to be done. Current efforts are underway to both expand the level of societal detail included within the models, along with increasing its ability to ingest and process real-time social media information and increasing its ability to couple with other military models designed to represent operational plans, scenarios, and operational orders.

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