MULTI-FORMALISM MODELING OF HUMAN ORGANIZATION

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ABSTRACT

The modeling of a human organization for the analysis of its behavior in response to external stimuli is a complex problem and requires development and interoperation of a set of several models. Each model, developed using different modeling languages but the same data, offers unique insights and makes specific assumptions about the organization being modeled. Interoperation of such models can produce a more robust modeling and simulation capability to support analysis and evaluation of the organizational behavior. Meta-modeling analysis based on Concept Maps and Ontologies indicates what types of interoperation are valid between models expressed in different modeling languages. The approach is illustrated through several examples focusing on the use of Social Networks, Timed Influence Nets (a variant of Bayes Nets), and Colored Petri nets.

FRAMING THE MULTI-FORMALISM MODELING PROBLEM

Modeling is the process of producing a model; a model is a representation of the construction and working of some situation of interest (Maria 1997). Figure 1 represents the modeling hierarchy where a Model is obtained using a Modeling Tool that applies a Modeling Formalism or Language to represent a specific Situation. The model itself should always conform to the Modeling Formalism used to create it.

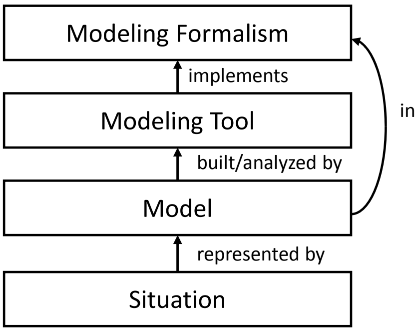

Figure 1: Modeling Hierarchy

Multiple models are used because each modeling formalism provides certain capabilities and makes specific assumptions about the domain being modeled. For example, Timed Influence Nets (Haider and Levis 2007) describe cause and effect relationships among groups at high level but have no capability of capturing social aspects among the groups of interest. Social Networks (Carley 1999), on the other hand, can describe the interactions among groups and members of the groups. In this context, a Multi-Formalism Modeling process addresses a complex problem through the use of a number of interconnected domain-specific models where each model contributes insights to the overall problem. The interoperations between the interconnected models could serve different purposes and can happen in various forms. The focus of this paper is on modeling human organizations.

Social scientists have been collecting and analyzing socio-cultural data to study social groups, organizations, tribes, urban and rural populations, ethnic groups, and societies. Sometimes the data are longitudinal (i.e., time series) tracking a particular social entity over a long time period and other times the data are taken at a single point in time (e.g., surveys) across a diverse population. Sometimes the data are focused on individual actors and their attributes and other times on the relations between actors. This poses a unique challenge: the classification and taxonomy of model types and how data relate to them, i.e., a taxonomy that can bridge the gap between data and models. This challenge is further exacerbated by the fact that no single model can capture the complexities of human behavior especially when interactions among groups or organizations with diverse social and cultural attributes are concerned.

Because the human behavior domain is very complex when observed from different perspectives, a classification scheme is needed that can place different modeling approaches and modeling formalisms in context, but in a way that is meaningful to empiricists who collect the data, to modelers that need data to develop and test their models, and to theoreticians who use model generated data to induce theoretical insights. As a start to the development of a taxonomy for the problem space, four dimensions are considered.

Mathematical and Computational Modeling Languages. There are many modeling languages and many classifications of them, e.g., static or dynamic, deterministic or stochastic, linear or nonlinear, continuous time or discrete

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time, time driven or event driven, quantitative or qualitative, agent centric or system centric, and so forth. On the basis of these modeling languages, different types of models have been developed: Bayesian networks, Social Networks, Dynamic Networks, Colored Petri Nets, State Machine models, Dynamics and Control models based on differential equations, System Dynamics models based on difference equations, Agent-Based models with internal sets of rules, Econometric models (time series based models), Statistical models, Input-Output (e.g., Leontieff) models, and many others.

Social Entity (Granularity). This is an important dimension because it addresses the issue of improper generalization of the data. Being explicit in specifying the characterization of the social entity that will be modeled and analyzed is essential. The social entity classification can range from an individual (e.g., the leader of a country, or a Chief Executive Officer, or a military leader) to a cell or team (e.g., an aircraft maintenance crew or a terrorist cell,) to a clan or tribe, to an ethnic or religious group, all the way to a multi-cultural population -- the society -- of a nation-state. There are serious definitional issues with regard to the social entity that need to be addressed by mathematical and computational modelers. These issues include spatial, temporal and boundary constraints; sphere of influence; change processes and rate of adaptation. For example, while the boundaries of an individual are impermeable, the boundaries of a tribe are permeable. Marriage enables crossing clan or tribal boundaries and, interestingly, in both directions. Individuals can be in only one location at a time; whereas, groups can have a very complex spatial-temporal presence (e.g., ranging from an agricultural cooperative to a transnational organization). As the granularity of the social entity increases, the size of the sphere of influence increases, the physical space covered increases, and the rate of adaptation decreases. For example, individuals can impact those within their communication network and adapt to new situations in minutes whereas a nation-state can influence other nation-states but may take years to adapt. Finally, the change processes are different with individuals changing as they learn and nation-states changing through processes such as migration, legislation, economic collapse, and war.

Scope of Problem. In the military domain, the types of decisions that are made are characterized as tactical, operational, and strategic. It used to be that tactical decisions concerned the present and immediate future, operational decisions the near term future, while strategic decisions concerned the long term (Fig. 2). However, information technology has changed this; it has made it possible for tactical decisions to have almost immediate strategic implications. The three levels have become very much coupled. For example, a terrorist act, itself a small tactical operation, can have significant strategic impact by changing the long term behavior of a population (e.g., the effect of an unsuccessful terrorist action on an airplane caused significant changes in air travel security worldwide.)

Time. The time attribute is complex and cannot be captured by a single variable. First, there is the time period that the data cover. This requires at least two variables: one is the location on the time line and the other is the duration of the period the data cover. Another possible attribute is the time interval between sampling instants. Second, there is the time dimension of the model itself. It can be an instant or a period.

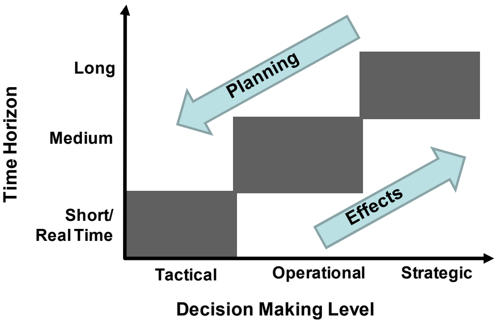

Figure 2: Problem Scope & Time Horizon

The choice of an instant leads to static models; the instant of time can be a year, a month, a week, or any other epoch. Essentially, a static description of an organization is developed that remains unchanged during that epoch. The other alternative is to consider a time interval over which the organization transforms. Again that time interval can range from hours to years. A key attribute of the time interval (duration) is its location on the timeline. Third, there is the time dimension that the model addresses. This is called the time horizon of the model.

The time dimension is closely related to the scope of the problem and is also related to the size of the social entity considered – as the time horizon is increased, the sphere of influence (i.e., the size of the social entity that will be impacted) is increased. Furthermore, the larger the social entity is, the longer the time horizon necessary to observe effects on the behavior. While exceptions to this rule are possible, this consideration also restricts the combinations of entity size and time horizon that define meaningful problems.

These four types of dimensions, modeling formalism, social entity, scope, and time, define the problem space for modeling the behavior of diverse types of human organizations. In many cases, the mathematical and computational models are created so that they can be used in developing strategies to effect change that will increase the effectiveness of the organization. In this case, proper handling of time is essential both in the model as well as in the underlying data. An additional challenge with respect to the temporal dimension(s) is to consider the persistence of effects on the targeted social entity; it is important to account not only for delays in an effect becoming observable, but also for its gradual attenuation over time.

Aspects of this construct can be represented graphically in a 3-dimensional space that has Social Entity, Time, and Modeling Formalism or Language, being the three axes. In the graphic in Fig. 3 some possible calibration of the axes is shown, but this is only illustrative. Social scientists and mathematical and computational modelers working together may refine the attributes that are marked on these axes and place them in a logical order. The Scope axis has not been included; the graphic of Fig. 3 can be interpreted as being for a given scope. Indeed, the choice of scope may lead to a re-calibration of the three axes.

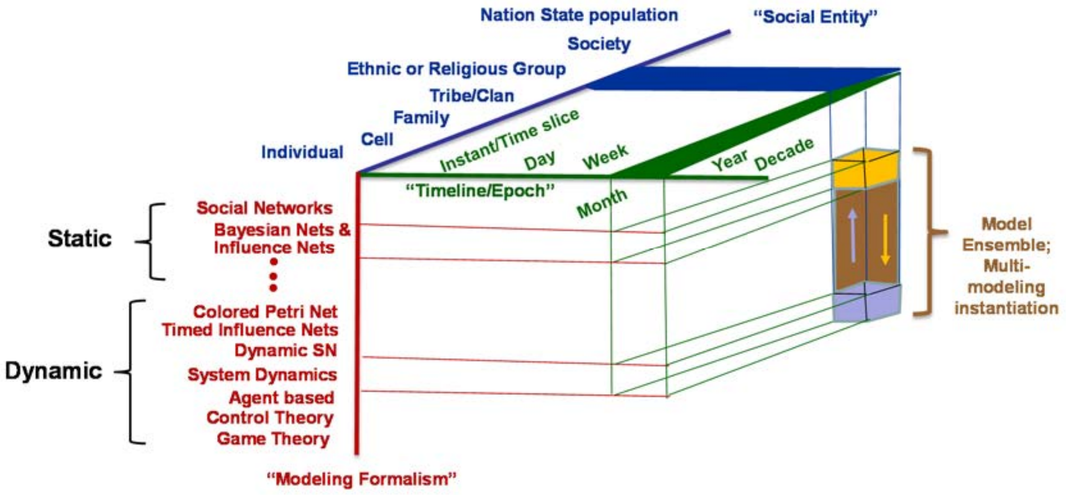

Figure 3: A Possible Classification Scheme for Multi-Formalism Modeling

Given a classification scheme and the appropriate ordering, then we can define a set of feasible cells in that space. Each cell then defines a particular model by specifying three attributes: (a) the social entity being modeled, (b) the epoch being considered, and (c) the modeling formalism or language. Not all cells in the space may be of interest in the sense that no problems addressing the situation of interest have been identified for that combination of attributes. Also, some mathematical and computational models, by their basic assumptions, may not be able to be associated with specific values of the other axes. For example, agent based models are not appropriate for modeling a single individual so the corresponding set of cells would be empty. Within each cell there may be multiple models depending on the problem scope.

The classification scheme selected for each axis should make sense with respect to the problem/issue domain. A particular challenge faced earlier while modeling the dynamics of a province in Iraq with a set of externally provided data is that terrorist organizations exist and operate amidst civilian (non-combatant) populations. Since no single model can capture well both the terrorist cell dynamics and the non-combatant population behavior, a set of interoperating models was needed. In another example, the impact of a course of action focused on de-escalating a crisis between two nation states with nuclear capability (e.g., Pakistan and India) needed to be assessed. An ensemble of models, each using different modeling formalism, was used to explore the impact of applying the de-escalatory strategy on the behavior of the two governments.

MULTI-FORMALISM MODELING CHALLENGES

The classification scheme of Fig. 3 would act as the first filter that would show which "cells" are available for possible use (i.e., which modeling formalisms) based on the scope, social entity, and time dimension of the issue being considered and which ones are not appropriate for use because of granularity or temporal considerations.

Suppose now that a set of non-empty cells have been identified in Fig. 3 that could be used to address the problem of interest. The existence of multiple modeling alternatives leads to a set of questions: (a) What data are required for each modeling formalism and are that data available; (b) will the selected models run independently or will they interact or inter-operate? (c) If they interoperate, what form will the interoperation take?

Note that model interactions can take a wide variety of forms: (1) Two models run in series with the output of one providing an input to the other; (2) One model runs inside another; (3) Two models run side-by-side and interoperate. The interoperation can be *complementary* where the two run totally independently of each other supplying parts of the solution required to answer the questions, or *supplementary* where the two supply (offline and/or online) each other with parameter values and/or functionality not available to either individual model; and (4) One model is run/used to construct another by providing design parameters and constraints or to construct the whole or part of another model. These are all aspects of the need for *semantic interoperability*.

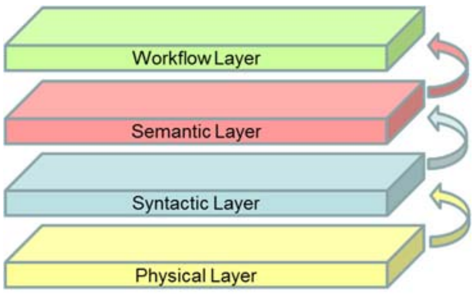

Figure 4: The Four Layers of Multi-Formalism Modeling

In order to address in a structured manner the modeling and simulation issues that arise when multiple models are to interoperate, four layers need to be addressed (Fig. 4). The first layer, the *Physical Layer*, i.e., Hardware and Software, is a platform that enables the concurrent execution of multiple models expressed in different modeling languages and provides the ability to exchange data and also to schedule the events across the different models. The second layer is the *Syntactic Layer* which ascertains that the right data are exchanged among the models. Once this is achieved, a third problem needs to be addressed at the *Semantic Layer*, where the interoperation of different models is examined to ensure that conflicting assumption in different modeling languages are recognized and form constraints to the exchange of data. In the *Workflow Layer* valid combinations of interoperating models are considered to address specific issues. Different issues require different workflows. The use of multiple interoperating models is referred to as Multi-Formalism Modeling MFM) while the analysis of the *validity* of model interoperation is referred to as Meta-Modeling. Each of these layers and the challenges that they pose are addressed in the next section.

THE MULTI-FORMALISM MODELING LAYERS

The Physical and Syntactic Layers

The technical issues regarding the Physical and Syntactic Layers have been resolved a decade ago. There are numerous testbeds, based on different principles, which enable the inter-operation of models. For example, SORASCS, developed at CASOS at Carnegie Mellon University used a Service Oriented Architecture (SOA). (Garlan et al. 2009) The C2 Wind Tunnel (C2WT) on the other hand is an integrated, multi-modeling simulation environment. (Hemingway et al. 2011; Karsai et al. 2004) Its framework uses a discrete event model of computation as the common semantic framework for the precise integration of an extensible range of simulation engines, using the Run-Time Infrastructure (RTI) of the High Level Architecture (HLA) platform. The C2WT offers a solution for multi-model simulation by decomposing the problem into model integration and experiment or simulation integration tasks as shown in Fig. 5.

Model Integration: Integrated experiments or simulations are specified by a suite of domain specific models, including for instance: human organizations (expressed using the Colored Petri Net modeling language and social networks), networks (OMNET++ network simulation language), physical platforms (Matlab/Simulink based models), and the physical environment (e.g., Google Earth). While the individual behaviors simulated by the different simulation models are essential, they must interact as specified by the workflow for the particular simulation or experiment. Their interactions need to be formally captured and the simulation of the components needs to be coordinated. This is a significant challenge, since the component models are defined using dramatically different domain specific modeling languages. The C2WT, therefore, uses the meta-modeling technology and the Vanderbilt MIC tool suite[1]. The key new component is the Model Integration Layer (Fig. 5), where a dedicated Model Integration Language (MIL) is used for model integration. The MIL consists of a carefully selected collection of modeling concepts that represent the domain-specific simulation tools. An additional feature of the C2WT is its ability to include human-in-the-loop architectures whether in the roles of operators (piloting drones) or playing the roles of decision makers.

Model-based Experiment Integration: C2WT uses the MIC model interpretation infrastructure for the generators that automatically integrate heterogeneous experiments on the HLA platform deployed on a distributed computing environment. After finalizing the component models, the integration models, and setting the parameters, the MIL model interpreters generate all the necessary configuration information and run-time code. Each modeling language is depicted as a federate on which models built using that language run.

Time Management: It is critical to preserve causality with simulations operating at different timescales. The C2WT builds upon the time management features of the un-

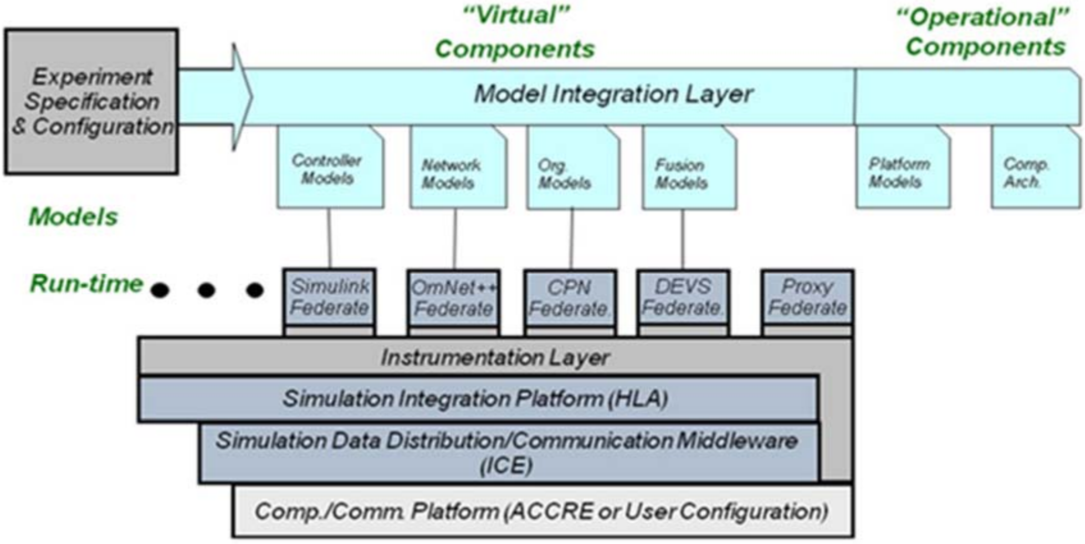

Figure 5: The C2WT architecture

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[1] MIC is a meta-programmable Model-Integrated Computing (MIC) tool suite for integrating models, to manage the configuration and deployment of scenarios in the simulation environment, and to generate the necessary interface code for each integrated simulation platform. It has evolved over two decades of research at the Institute for Software Integrated Systems at Vanderbilt University and is now used in a wide range of government and industry applications.

derlying HLA standard, which has provision for both discrete time and discrete event models. The main elements of time management in HLA are: a) a Logical Timeline, b) Time ordered delivery of interactions between simulations, and c) a protocol for advance of Logical Time. In a causality preserving execution (note that HLA supports untimed executions as well), the underlying RTI maintains a logical time, and interaction messages generated by simulations are time stamped with the logical time and delivered to their destinations in a timed order. The logical time is advanced by a cooperative Time Advance Request and Grant protocol. A similar protocol is supported for event driven simulations in which the event driven simulation requests the Next Event to the RTI. The simulation logical time is advanced either to the earliest available interaction or to the time stamp of the next event local to the requesting simulation.

One can also envision a federation of two or more of these test bed infrastructures through the incorporation of the different modeling languages as federates. However, while this is sufficient to enable the passing of data from one model to another and for the computational and syntactical interoperation of models, it is not sufficient to ensure the semantic and mathematical/algorithmic interoperability. For that, basic research was needed on meta-modeling.

The Semantic Layer and Meta-Modeling

A Meta-Model is an abstraction layer above the actual model and describes the modeling formalism used to create the model. Consequently, a model has to conform to its meta-model in the way that a computer program conforms to the grammar of the programming language in which it is written. Meta-Modeling is defined to be the process of constructing a meta-model in order to model a specific problem within a certain domain. The typical role of a meta-model is to define how model elements are instantiated.

In an effort to study and formally represent the semantic interoperability of disparate models and modeling languages, Rafi (2010) and Levis et al. (2010) have developed a meta-modeling framework. This meta-modeling approach extends earlier works by Kappel et al. (2006) and Saeki and Kaiya (2006) for a class of modeling languages primarily used for behavioral modeling problems.

The meta-modeling approach presented here is based on the analysis of the conceptual foundations of a model ensemble so that individual models constructed to address a specific problem in a domain of interest can be evaluated for possible interoperation. The interoperation may be in the form of possible use of the same input data and/or exchange of parameter values or analysis results across different models. This meta-modeling approach provides a framework for identifying these integration mappings between different modeling formalisms especially when they are employed to construct models addressing a common situation or problem of interest. It is a phased approach that uses concept maps, meta-models, and ontologies. It is based on comparing the ontologies (for each modeling technique) to help identify the similarities, overlaps, and/or mappings across the model types under consideration. The modeling languages considered thus far are Social Networks, Dynamic Meta-Networks and probabilistic decision models such as Influence and Timed Influence Nets. Additional work has been done for Colored Petri Nets modeling decision making organizations and discrete event communication system models.

The approach starts by specifying a modeling paradigm by constructing a generalized Concept Map (Novak and Cañas 2008, IHMC 2014) that captures the assumptions, definitions, elements and their properties and relationships relevant to the paradigm. An example of a Concept Map for a Timed Influence Net, a variant of Bayes nets, is shown in Fig. 6. This concept model is a structured representation, albeit not a formal one, and, therefore, not amenable to machine reasoning.

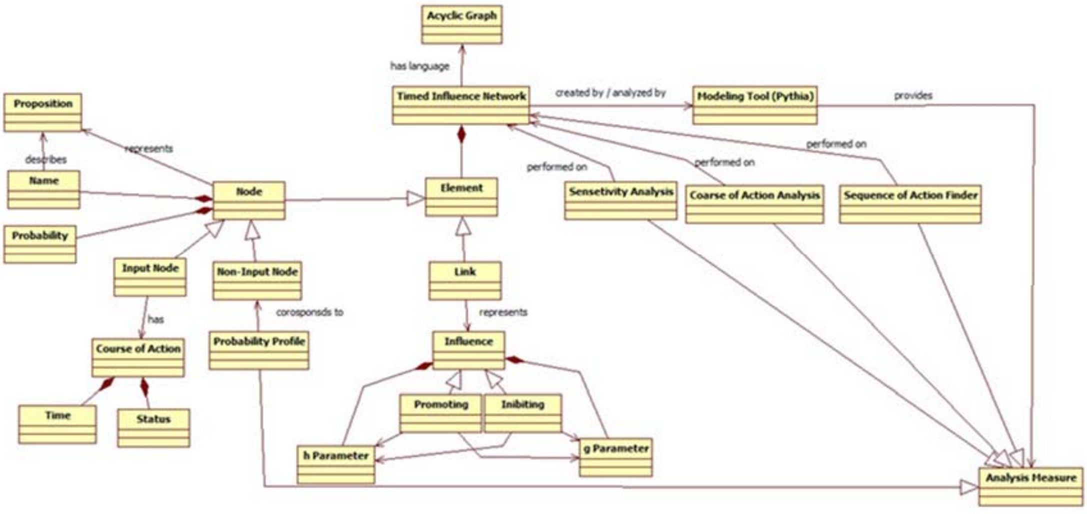

Figure 6: Concept Map for Timed Influence Nets (TIN)

The Concept Map representation is then formalized using meta-models. This is shown in Fig. 7 where the Concept Map for TIN has been expressed formally using the Unified Modeling Language (UML). The aim of constructing the meta-model is to reveal the structural (i.e., syntactic) aspects of the modeling formalism and to lay down the foundation for its ontology.

A basic ontology, referred to as a *pseudo ontology*, is constructed which mirrors the meta-model and serves as the foundation ontology; it does not contain any semantic concepts (related to the modeling formalism and to the modeled domain) but acts as the skeleton for the ontology.

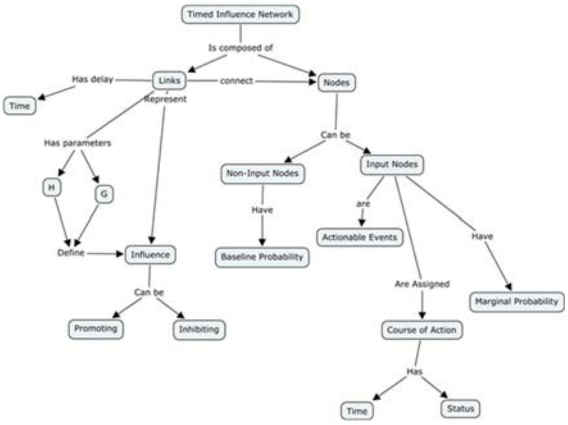

Figure 7: The TIN Concept Map Expressed in UML

The next step, semantic concepts and relationships are added to this foundation ontology to obtain the *refactored ontology*. Once the individual ontologies are completed for each modeling technique, mapping of concepts across the ontologies is started. The resulting ontology which contains these concepts and relationships within and across multiple ontologies is called an *enriched ontology*.

Figure 8 provides an overview of the workflow prescribed by the meta-modeling approach when applied to two modeling formalisms: Timed Influence Nets and Social Networks. The enriched ontology so constructed for the modeling formalisms can be reasoned with using the logical theory supporting the ontological representation (Bechhofer 2003). This mapping suggests ways in which several modeling formalisms can interoperate on a multi-model integration platform such as the C2WT. The mappings suggest possible semantically correct ways to ensure consistency and to exchange information (i.e., parameter values and/or analysis results) between different types of models when they are used in a workflow solving a specific problem of interest.

Analysis of the network structure of the Concept Map can provide guidance as to the conditions under which the Concept Map is sufficiently complete to assess model interoperability. For example, social network metrics may be used; Concepts Maps can be imported in a tool such as ORA for assessment (Carley et al. 2013). Furthermore, by comparing the network structure of Concept Maps for different modeling formalisms it may be possible to identify previously unidentified connections among the resulting models.

Meta-Modeling analysis indicates what types of interoperation are valid between models expressed in different modeling formalisms. Two models can interoperate (partially) if some concepts appear in both modeling formalisms and they have no contradictory concepts that are that are invoked by the particular application. By refining this approach to partition the concepts into modeling formalism/language input and output concepts and also defining the concepts that are relevant to the questions being asked to address the problem, it becomes possible to determine which sets of models can interoperate to address some or all of the concepts of interest, and which sets of models use different input and output concepts that are relevant to those questions.

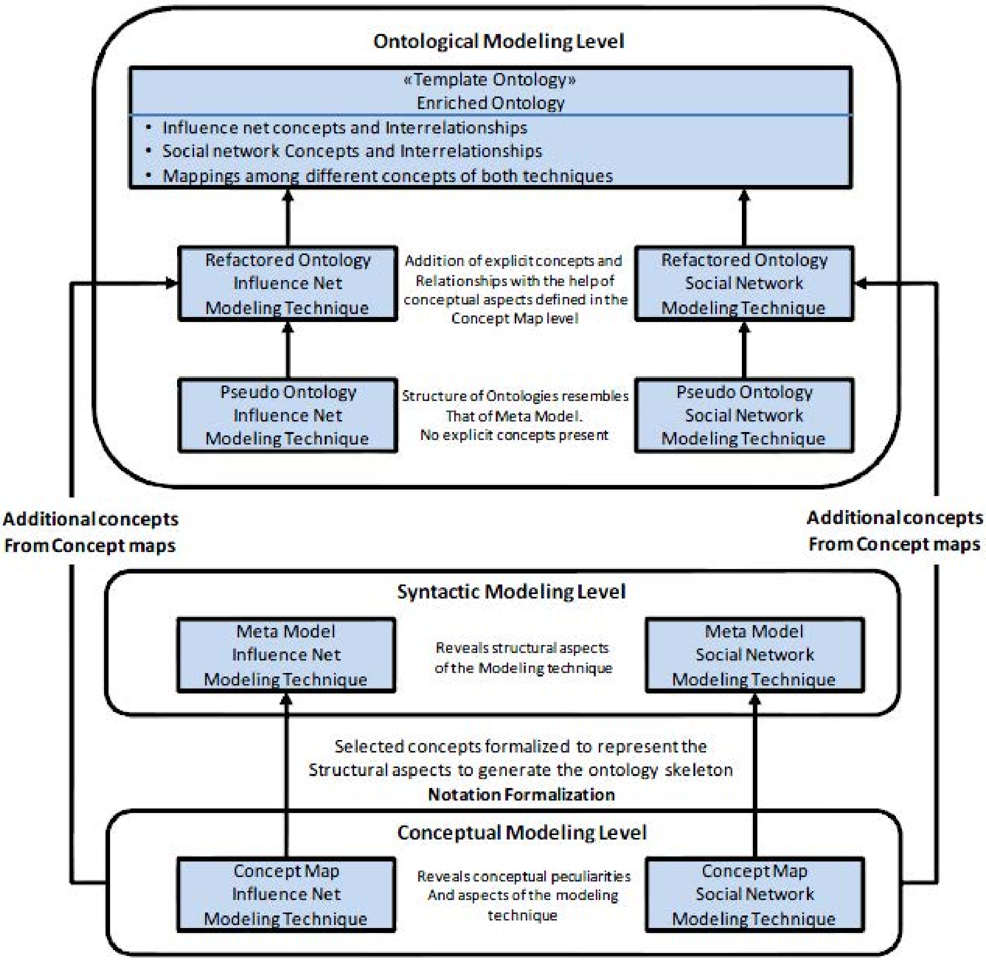

Figure 8: Overview of the Meta-Modeling Approach

In order to support *semantic interoperability* models will need to be interchanged across tools. This requires model transformations. The transformations are formally specified in terms of the meta-models of the inputs and the outputs of the transformations. From these meta-models and the specification of the semantic mapping a semantic translator that implements the model transformation is synthesized. (Emerson and Sztipanovits 2006)

The Workflow Layer

In achieving Multi-Formalism Modeling (MFM), and to provide supporting platforms, many challenges have to be faced. Beside the technical issues that usually arise in allowing interoperations between models through their modeling tools, as described in the previous sub-sections, there is also a major challenge of improving the human interface to the MFM process itself (Fishwick 2004).

A systematic methodology for developing and then using a Domain Specific MFM Workflow Language (DSMWL) is needed. The objective is to help users of MFM platforms in creating workflows of modeling activities while guaranteeing both syntactic and semantic correctness of the resulting ensemble of inter-operating models. The approach is domain specific; the rationale behind this is twofold: first, problems to be solved by employing MFM techniques are usually domain specific themselves; second, it narrows down the scope of meaningful interoperations among several modeling formalisms where each formalism offers unique insights and make specific assumptions about the domain being modeled. The first step consists of the identification and characterization of a domain of interest and the modeling techniques that support it. This defines a region in containing a number of non-empty cells in the construct of Fig. 2. Domain Analysis follows; its aim is to provide formal representations of syntactic and semantic aspects of the domain. A new Domain Specific MFM Workflow Language is then developed to construct workflows that capture MFM activities in the selected domain. A domain Ontology resulting from the Domain Analysis step is utilized to provide semantic guidance that effects valid model interoperation.

Domain Specific Modeling Languages (DSMLs) are languages tailored to a specific domain. They offer a high level of expressiveness and ease of use compared with a General Purpose Language (GPL). Development of a new DSML is not a straightforward activity. It requires both domain knowledge and language development expertise. In the first place, DSMLs were developed simply because they can offer domain-specificity in better ways. According to Mernick at al. (2005), the development of any new DSML should go in five phases: Decision, Analysis, Design, Implementation and Deployment. The details of the process for developing a DSMWL are documented in Abu Jbara (2013) and Abu Jbara and Levis (2014).

Creating workflows using a domain specific language allows for translating visual views of model interoperation into an executable implementation. There already exist generic techniques for creating and executing workflows such as BPMN (OMG-BPMN 2011) and BPEL (OMG-BPEL 2011). The domain specific nature of the MFM approach requires the development of a Domain Specific MFM Workflow Language for the selected domain of interest. Such a language would be tailored to a problem domain of interest and would offer a high level of expressiveness. It can be a specific profile of an existing GPL, i.e., BPMN.

The Approach

For effective use of Multi-Formalism Modeling, all four layers are necessary. Implementation of the physical and syntactic layers results in a computational testbed; the semantic layer through metamodeling analysis addresses the validity of model interoperation; and the workflow layer, through the Domain Specific Multi-Formalism Modeling workflow languages it contains, enables the construction and management of a particular multi-formalism construct to address the problem of interest. Based on this foundation, it is possible now to consider a number of different modeling formalisms that can be used to explore questions involving human organizations.

MODELING HUMAN ORGANIZATIONS

A suite of modeling tool sis shown in Fig. 9, each tool conforming to a different modeling formalism. They have been developed by the System Architectures Laboratory (SAL) of George Mason University and the Center for Computational Analysis of Social and Organizational Systems (CASOS) of Carnegie Mellon University.

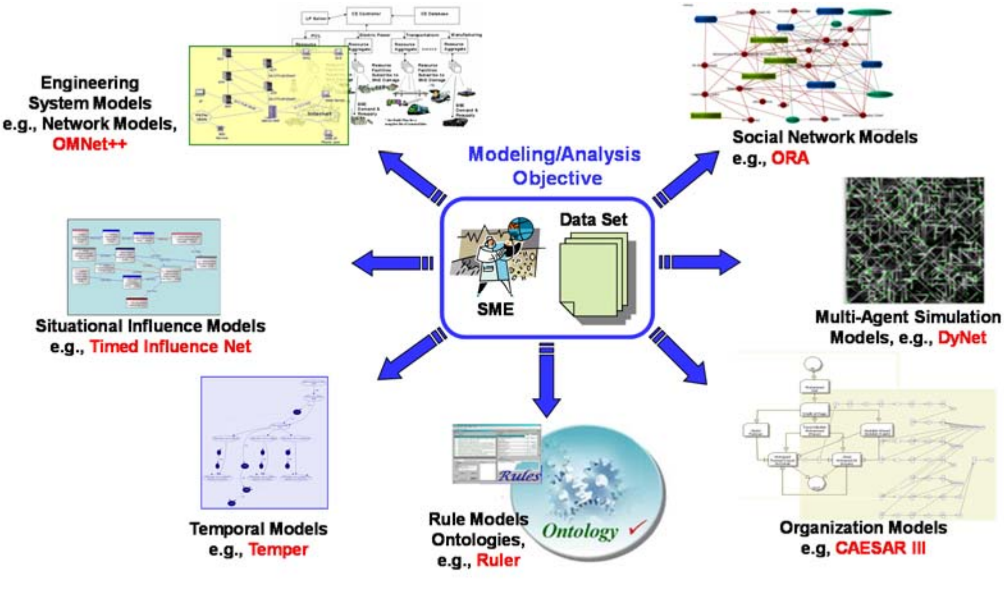

Figure 9: Tools for Modeling Human Organizations

For example, Social Networks (Carley 1999) describe the interactions (and linkages) among group members but say little about the underlying organization and/or command structure. **ORA** (Carley et al. 2013) is an application for the construction and analysis of social networks, while ***DyNet*** (Belov et al. 2009) is a multi-agent simulation model for studying dynamic changes in human networks.

Similarly, organization models (Levis, 2005) focus on the structure of the organization and the prescribed interactions but say little on the social/behavioral aspects of the members of the organization. ***Caesar III*** is a Colored Petri Net tool for designing and analyzing organizational structures. (Levis et al. 2008). Policies and procedures that govern the behavior of an organization need to be modeled and analyzed because they affect the behavior of the human organization. ***Ruler*** is a tool for evaluating whether a proposed course of action is in compliance with the prevailing policies and procedures. (Zaidi and Levis 1997) ***Temper*** (Zaidi and Levis 2001) is a temporal logic inference tool that is used to address the temporal aspects of a course of action.

Timed Influence Net (TIN) models (Wagenhals and Levis 2007, Mansoor et al. 2009) are a variant of Bayesian models, used to describe cause and-effect relationships among groups at a high level. The Timed Influence Net application, ***Pythia*** (Levis 2014), is used to develop Courses of Action and compare their outcomes.

In addition to these tools, existing tools can be incorporated such as a tool for modeling communications networks (e.g., the open source OMNeT++ (2014) and the INET Framework (2014)).

INTERDICTION OF DRUG TRAFFICKERS

In this section, an application of the Multi-Formalism Modeling approach to problems involving human organizations is described. It is based on the operations of an actual organization, the US Joint Interagency Task Force – South, whose mission is interdiction of drug trafficking in the southeastern part of the US. The scenario was inspired by a motion picture: *Contraband* (2012). It uses three modeling formalisms: Social Networks with **ORA**; Colored Petri Nets with **CAESAR III**, and Timed Influence Nets with **Pythia** as well as a geographic visualization system.

JIATF-South is a Drug Interdiction agency well known for interagency cooperation and intelligence fusion. The agency usually receives disparate data regarding drug trafficking from different sources. Quick and effective analysis of data is essential in addressing drug trafficking threats effectively. A typical case begins with JIATF-South receiving information form the US Drug Enforcement Administration. This prompts the deployment of drones that subsequently detect and monitor a suspect vessel until JIATF-South can sortie a Coast Guard cutter to intercept. If drugs are found, jurisdiction and disposition over the vessel, drugs, and crew are coordinated with other national and international agencies. Courses of Action (COAs) identified by JIATF-South are fully dependent on efficient analysis of received data. Analysts at JIATF-South are trained to use various modeling techniques to analyze data and then to identify possible COAs. By applying the MFM approach, analysts should be capable of creating visual workflows supported by interoperating models. An informal description of the domain is as follows:

- Drug Interdiction involves information sharing, fusion of intelligence data, and monitoring of drug trafficking activities.
- Given incomplete and uncertain information, timely decisions to be made on best Courses of Action.
- Drug Interdiction involves dealing with Drug Cartels and Smugglers and Law Enforcement and Intelligence.
- Drug Smugglers takes different routes and originate from different geographical points.
- Analysts use Social Networks, Organization Models Influence Nets, GIS, and Asset Allocation and Scheduling techniques.

After identifying related concepts, a Concept Map is constructed to capture the relations between the concepts. Figure 10 shows a concept map that addresses the question: How does JIATF-South perform Drug Interdiction?

Domain Analysis follows by using the generated concept maps to construct UML class diagrams that represent the constructs of the domain. Using GME, a Meta-Model for this domain's Workflow MFM Language is defined based on the UML class diagram resulting from the domain analysis. This Meta-Model defines the constructs of this new language. Figure 11 shows part of the visualization aspect of the Domain Specific MFM Workflow Language. In addition to the basic constructs borrowed from BPMN, some new constructs have been introduced and some constraints have been imposed. The resulting workflow has two types of activities, operations and interoperations. Operations are those activates performed on a specific model using the modeling tool that supports its modeling formalism. Interoperations are those activities that involve interoperations across models through their modeling tools. Operations in this DSMWL can be in one of two flavors, Thick or Thin. This is due to the fact that multi-modeling platforms can support the integration of modeling tools in one of two forms. Thin Operations represent the case when service based integration takes place, given that the modeling tool of interest exposes its functionalities as services. Thick Operations represent the case in which the whole modeling tool is integrated as a package in the multi-modeling platform.

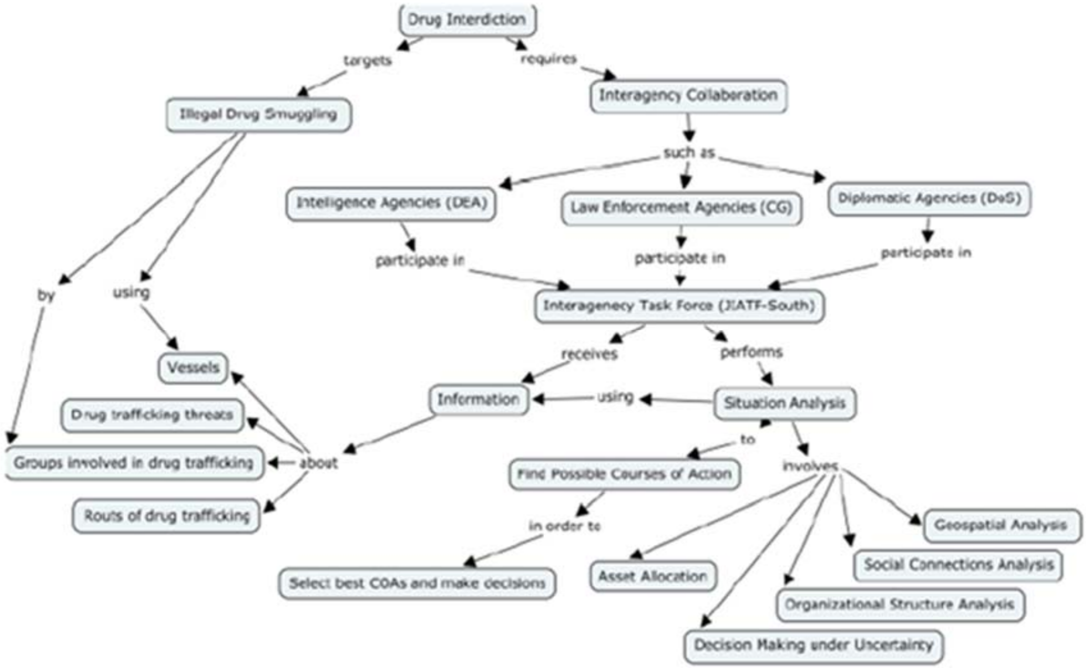

Figure 10: Concept Map for Drug Interdiction

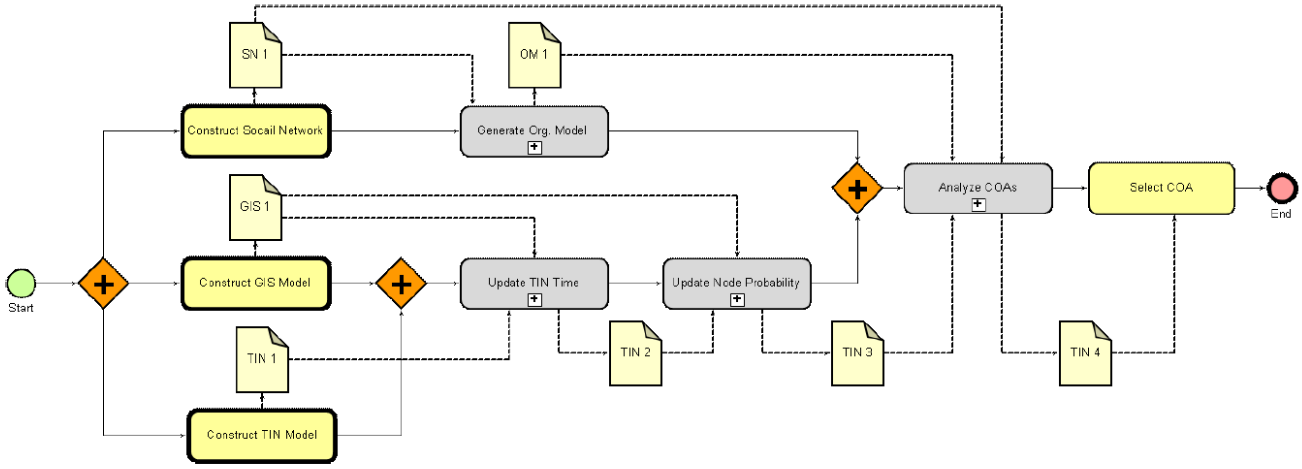

Figure 11: Workflow of drug interdiction MFM activity expressed in the Domain Specific MFM Workflow Language

Once the GME meta-model of the constructed Domain Specific Multi-Modeling Workflow Language is interpreted and registered as a new modeling paradigm in GME, the GME environment is used to create workflows that capture specific domain scenarios. Figure 11 shows a workflow that involves the use of Geospatial models, Timed Influence Nets, Social Networks and Organization Models to analyze data and then generate and select best Courses of Actions (COAs) for drug interdiction.

The Fictitious Scenario: The JIATF-South agency receives information about suspicious activities from different sources including local, regional, and international intelligence agencies. The scenario events begin when a cargo ship with R flag (R is a country in the Caribbean) is being loaded with drugs.

A drug cartel operating in country R is responsible for this drug smuggling activity. The local intelligence agency of country R intercepts a phone call between a person known to be the head of the cartel in country R and a customs officer in R's port authority. R's intelligence agency shares information with JIATF-S; its officers react directly and begin analyzing the information. The suspected drug cartel in country R is already known to the officers. It is also known that this R-based cartel is connected to a US-based cartel. JIATF-S has an insider informant in the US-based cartel; the informant is requested to provide more information about this particular case. The cargo ship leaves the port of country R on Day n and enters international waters on day n+1. JIATF-S has drones that continuously monitor suspicious activities. Orders go out from JIATF-S directing some drones to monitor the suspected cargo ship and to keep it under surveillance. The cargo ship is expected to arrive to a US port on the Gulf of Mexico on day n+5. A visualization of the scenario is shown in Figure 12.

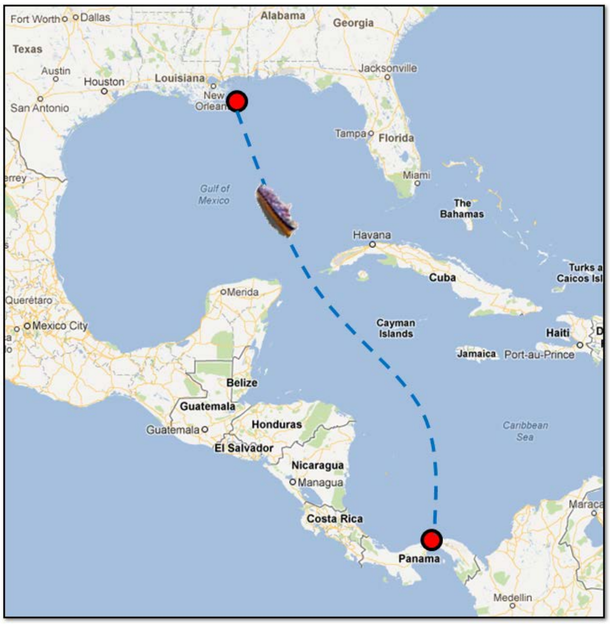

Figure 12: Scenario Visualization

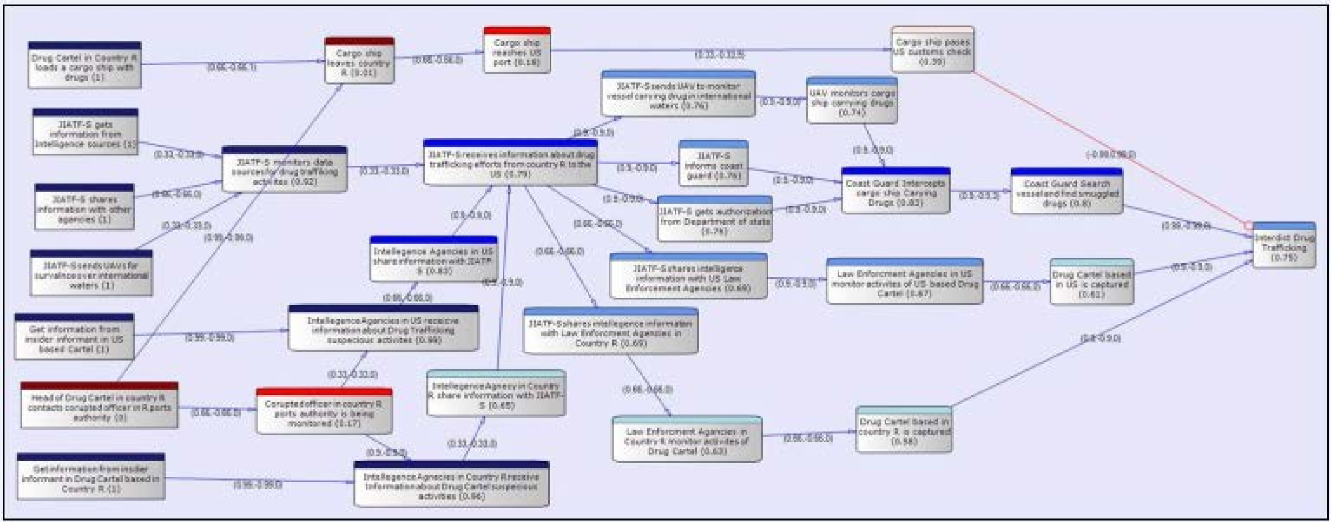

Figure 13: Timed Influence Net Model for Developing Drug Interdiction Courses of Action

Based on the information available, JIATF-S analysts construct a TIN model using Pythia and use it to analyze the effects of actions taken to address the drug trafficking threat in this scenario. Figure 13 shows the model created and analyzed as part of the scenario workflow. The goal, as shown on the node on the right side of the model, is to interdict drug trafficking activity. The actions that can be taken by JIATF-S and other scenario actors are shown on the left side of the model. Pythia has the capability to analyze the effect of setting each of these actions on or off and determining the optimum time for applying these actions. TIN analysis results in a set of probability profiles for each of the effects of interest when a particular Course of Action is applied. The COA that maximizes the probability of the goal node, interdicting drug trafficking in this case, is considered to be the best COA. This was obtained using the SAF optimization algorithm embedded in Pythia**.** The selected COA identifies which actionable events influence the success of drug trafficking efforts.

A Social Network model captures relationships between agents. JIATF-S receives continuous information about drug cartels and their members. With the help of ORA, relationships between cartel's members and among different cartels are captured (Fig. 14). These networks can help to identify the most effective individuals, "leaders," and the paths of communication between different cartels. Figure 14 shows a simple Social Networks for the cartels involved in the scenario. The nodes on the left side of the model represent the cartel based on country R while the nodes on the right represent the US based cartel. The arrows represent the relationships between the individuals and help to identify the most connected and influence individuals. These kinds of relationships and information captured in social networks help JIATF-S analysts to identify best actions to track and interdict drug trafficking activities taken by these two cartels. In the scenario workflow, a social network is used to generate an organization structure that is modeled as a Colored Petri Net using **CAESAR III** for further analysis and then to revise the TIN model before using it to generate COAs.

After the workflow of the interoperating models is interpreted, it gets executed on the testbed. The participating modeling techniques are utilized through their supporting tools that are already integrated into the computational platform. The focal point of the models is the TIN model. The workflow sequence operates on revising and optimizing this TIN model for better COA analysis and selection. Interoperations between models participating into the multi-modeling activity enhance the analysis process. The relationships captured in the social network model identify the most influential actors in the drug trafficking effort and are used to update the TIN model actions and probabilities. Temporal information captured in the geospatial model is used to update the timing of actions in the TIN model. After the TIN model is refined based on the data received from the other models, Pythia capabilities and algorithms are utilized for COA selection.

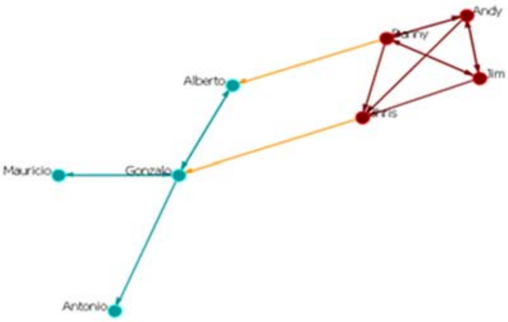

Figure 14: Social Network of Country R and US Drug Cartels

The last operation of the workflow, as was shown in Figure 11, represents the COA selection task. Different combinations of action events are examined to determine the COA that gives highest probability for a specific node goal, which is successful drug interdiction in this scenario. Three generated COAs are presented to illustrate the types of results obtained.

The first COA, visualized in Fig. 15, shows that sharing information between the JIATF-South and other (local and regional) intelligence agencies in addition to the utilization of surveillance resources, results in the probability of the target node of effective drug interdiction reaching its highest level around 68%. This is the selected COA by JIATF-S since it maximizes the probability of Drug Interdiction for the scenario under consideration.

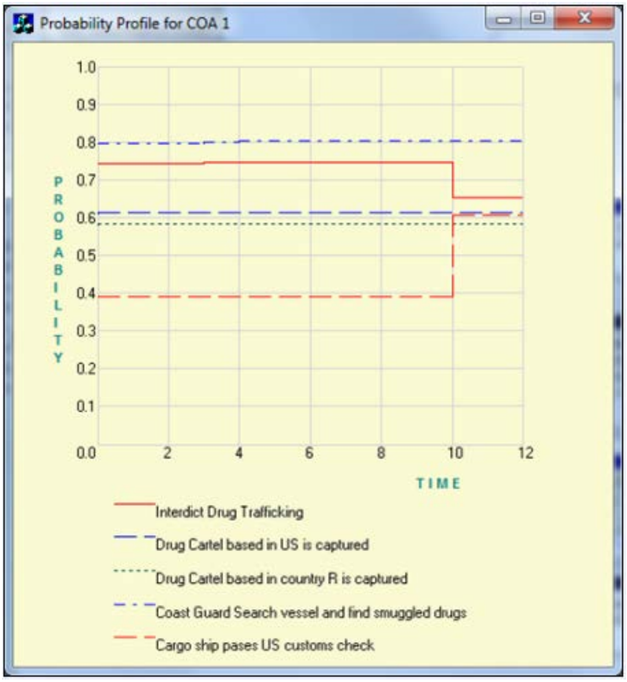

Figure 15: Best Course of Action

In the second COA (Fig. 16), the probability of interdicting smuggled drugs decreases dramatically to about 32% when information sharing between the JIATF-South and other local and regional intelligence agencies is not in effect. *This shows the value of information sharing to the success of drug interdiction efforts*.

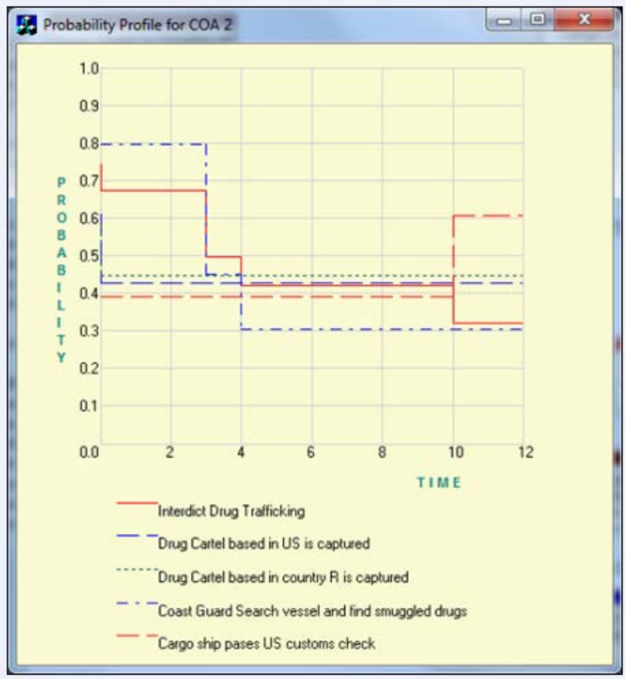

Figure 16: Second Option for Course of Action

The third COA (Fig. 17) shows how the probability of effective drug interdiction can decrease even more to a level close to 25% if in addition to lack of information sharing, insider information from the drug cartel is not available.

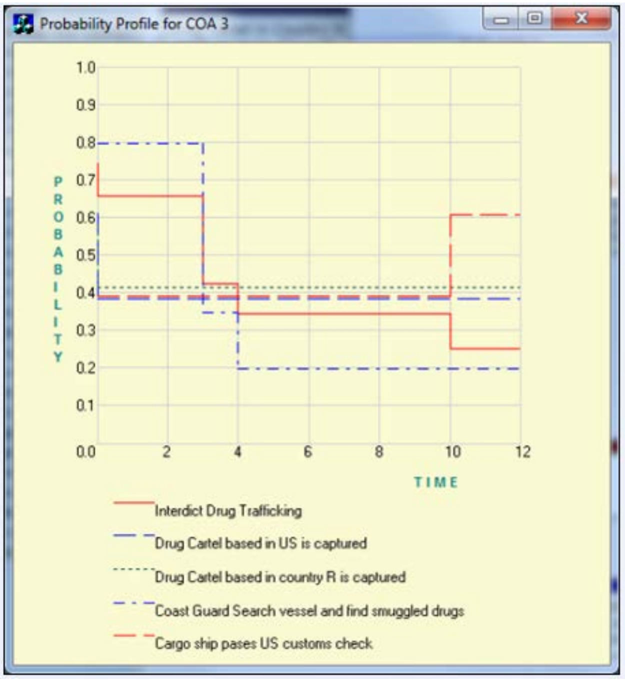

Figure 17: Third Option for Course of Action

CONCLUSION

A methodology for employing multi-Formalism modeling effectively has been described. The four layers of the approach have been identified and the issues that need to be considered at each layer have ben described. The approach has been used in a number of diverse applications where a variety of different modeling formalisms have been employed. One particular application focused on the interactions of human organizations is included to illustrate the process.

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