Cultural Geography Model Validation

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ABSTRACT: *In the current warfighting environment, the military needs robust modeling and simulation (M&S) to support Irregular Warfare (IW) analysis across the range of tactical, operational, and strategic levels of warfare to help inform decisions concerning operations within the IW environment. In support of this need, the military requires a responsive family of Models, Methods, and Tools (MMT) able to credibly represent US and Coalition ground forces conducting operations in a Joint and Combined IW environment, from the tactical to strategic levels. As a first step in this direction, TRAC Monterey (TRAC-MTRY) is developing a prototype capability that credibly represents ground forces conducting IW operations and focusing on the relevant relationships and interactions within the population. This paper describes work being performed on behalf of TRAC-MTRY to develop a measurable, repeatable method for assessing, understanding, and describing the risk of using an M&S for analysis, to enhance the ability of decision makers to assess the risk in using an IW M&S, and add to the core body of knowledge in Validation Best Practices.*

1. Introduction

In the current warfighting environment, the military needs robust modeling and simulation (M&S) to support Irregular Warfare (IW) analysis across the range of tactical, operational, and strategic levels of warfare to help inform decisions concerning operations within the IW environment. Violent extremist networks, which are tactful, complex adaptive systems with the outward appearing ability to act without direction are implicit within IW. Appropriate and meaningful responses to these violent extremist networks require understanding of the underlying population, its dynamics, and its driving forces. In support of this need, the military requires a responsive family of Models, Methods, and Tools (MMT) able to credibly represent US and Coalition ground forces conducting operations in a Joint and Combined IW environment, at the tactical to strategic levels. As a first step in this direction, TRAC Monterey (TRAC-MTRY) is developing a prototype capability that credibly represents ground forces conducting IW operations and focusing on the relevant relationships and interactions within the population. To this end, TRAC-MTRY has developed the Cultural Geography Model (CGM), a government owned, open source multi-agent system utilizing Bayesian networks, queuing systems, the Theory of Planned Behavior, and Fischer's Narrative Paradigm, as a first step in the development of a family of models to support the defense analyst in answering questions relevant to IW such as "Is security adequate?", "Will the outcome of upcoming elections be legitimate?" or "Will the presence of troops increase civilian violence?" with responses similar to polling data (Alt et al 2009 – JDMS pre-pub copy). Effective validation of models within this context requires progress in the theory of validation. This paper reports on the necessary background required to support work being performed on behalf of TRAC-MTRY to develop a measurable, repeatable method for assessing, understanding, and describing the risk of using an M&S for analysis, to enhance the ability of decision makers to assess the risk in using an IW M&S, and add to the core body of knowledge in Validation Best Practices.

2. Modeling IW

The M&S of IW requires the development of new M&S methods. The social science on which this development hinges is in its infancy. In particular, the social science is often biased by western perspectives in many areas; includes multiple theories to describe the same phenomena, often uncorrelated and sometimes contradictory; and lacks empirical data and underlying computable, mathematical structures to inform and validate modeling efforts. In fact, the data that is available is often qualitative vice quantitative and the relationships between available quantitative data and its effects on the social systems of interest are unknown (e.g., the human engagement that occurs between military units and the population, and its mutual relationship with DIME/PMESII at higher levels over time). Even in well understood, homogeneous populations, population modeling is difficult because of the complexity of human cognition. Heterogeneous, unfamiliar populations only exacerbate this problem. A method is needed to assess the available data, social science, and the developed M&S in a measurable, repeatable way for assessing, understanding, and describing the risk of using an M&S for analysis. Development of this risk assessment method is a key element in Validation Best Practices.

2.1 Validating IW models

The DoD guidance for accomplishing VV&A is well known and documented. While results validation and face validation are often used methods for the validation of models, the difficulties with this approach for simulations having sensitivity to initial conditions, chaotic, or emergent effects, and the difficulties with validating human based representation models is well known (Harmon et al. 2002, Defense Modeling and Simulation Office 2006, Akst 2006, Moya et al. 2007). The validation literature consists mainly of validation approaches, paradigms, and techniques as well as specific validation applications and assessments. There is no mechanism guiding the appropriate selection of approach and techniques in a given M&S application. Progress is required that will lead to effective validation, supporting the need for developing "fundamental new approaches of conducting VV&A … [and] … developing new VV&A methods and techniques … [with] practical value" (Sargent et al. 2000).

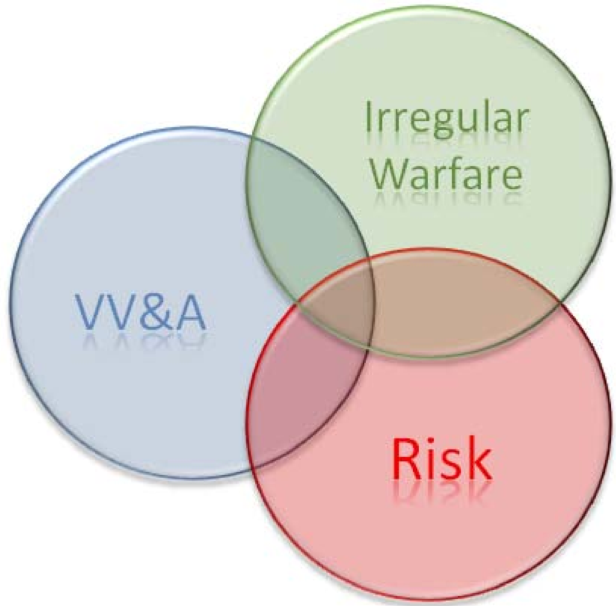
To address this need, the Marine Corps Combat Development Center (MCCDC) Operations Analysis Division (OAD) commissioned an Agent Based Simulation (ABS) Verification, Validation, & Accreditation (VV&A) Framework Study in 2008 to develop general, institutionally acceptable processes and criteria for assessing the validity of agent-based simulations used as part of DoD analyses with a focus to IW analyses. At its onset, this study focused on the concept of validity, viewing the verification process for simulation as the same as for software verification and accreditation as an agreement between analysts and the study sponsor that a particular model is useful for a particular analysis problem. It addressed the verification and accreditation processes with respect to their interdependencies with the validation process.

The MCCDC OAD effort focused on the validation of the non-physics based aspects of the validation problem with the goal to maintain the analytic rigor of the traditional VV&A process, while expanding it to cover non-traditional topics (e.g., population dynamics and cultural shifts). The effort demonstrated the validation process of ABS in two applications to guide the development of a framework that would provide a means for assessing the reliability, applicability and feasibility of the ABS for its intended use, preferably in a quantifiable way for future validation efforts. A key finding of this work is that the validation of an M&S for analysis cannot be decoupled from that analysis. The effort for TRAC-MTRY will leverage and expand on the MCCDC OAD effort in an applied way.

2.2 CGM validation project

The DoD requires robust IW modeling in the current environment. TRAC-MTRY is developing capabilities to help determine the potential impact of culture and the actions of the civilian population on current operations. As part of this larger effort, it is essential to have a validated conceptual model underlying the CGM reflective of the selected social science underpinnings. This project will develop a measurable, repeatable method for assessing, understanding, and describing the risk of using an M&S for IW analysis as well as develop validation methodologies for assessing the CGM conceptual model and implementation (Figure 2.1). It has the objective to assess the operational utility of the CGM with suggestions for its analytical use that make the operational utility accessible and mitigate any issues within the uses of interest. It supports Key Tenets of the TRAC IW Campaign plan by enabling an incremental development cycle, with interim proof-of-principle and prototype applications ("build-use-learn-fix" approach) and fits within the MMT line of effort by supporting the development of a Validation and Verification (V&V) methodology that helps achieve useable capabilities as fast as acceptable risk and resourcing permit.

Figure 2.1. Problem Context



3. Validating Human Behavior Models

The validation of IW M&S for analysis lies within the intersection between the spheres of VV&A, IW, and Risk as shown in Figure 2.1. Developing core knowledge of the IW is the purview of our military specialists. The question of how VV&A may be applied within the IW sphere has been asked (reference to be added). Questions arising from the intersection of the VV&A and risk spheres are more often well-understood for physics-based or engineering models but less frequently so for M&S techniques such as agent-based simulation. The intersection of the risk and IW spheres is the domain of the art of warfare and out of scope for the technical discussion. The addition of risk to the analysis allows a more formal discussion of the usefulness and limitations of M&S derived information. Our focus is on the innermost intersection where these questions may be answered in a real way for the IW problem.

3.1 Validation importance

Acceptability and usability get at the key points for why validation is important: to establish the credibility of a simulation for a specified intended use (Modeling and Simulation Coordination Office 2004b). This includes determining that the simulation is correct and meets requirements through software engineering and other processes but is not limited to that. It also includes providing users with sufficient information to determine if the simulation can meet their needs as well as determining the simulation's capabilities, limitations, and performance relative to the real-world objects it simulates. User participation throughout the development process facilitates this confidence.

The DoD guidance for accomplishing VV&A is well known and documented. While results validation and face validation are often used methods for the validation of models, the difficulties with this approach for simulations having sensitivity to initial conditions, chaotic, or emergent effects, and the difficulties with validating human based representation (HBR) models is well known (Harmon et al 2002, Modeling and Simulation Coordination Office 2004b, Akst 2006, Moya et al 2008).

Understanding the validity of the M&S of physics based and engineering systems for a given use is well understood. Further, physics-based combat models have a long history of use. However, the M&S of IW requires the development of new M&S methods. Further, the social science on which this development hinges is in its infancy. In particular, the social science is often biased by western perspectives in many areas; includes multiple theories to describe the same phenomena, often uncorrelated and sometimes contradictory; and lacks empirical data and underlying computable, mathematical structures to inform and validate modeling efforts.

3.2 Necessary elements for HBR validation

The robust documentation of the conceptual model; testing; and the theoretical support, traceability and justification for assumptions facilitate user confidence. Using a well-defined, documented validation process supports model credibility. Using strong validation methodologies ensure that models are built on a solid framework of standardized organization, process, products, and techniques; and that they simulate accurate, consistent, and reproducible results. Without strong, documented methodologies, valid simulations may be rejected, invalid outcomes may be accepted, or simulations may be used improperly (e.g., outside of intended use or in opposition to embedded assumptions). Formal methods allow for the precise description of a simulation's capabilities. Further, the ability to make general statements about individual, general, and federated models facilitates use and re-use of those models.

Any effective validation methodology needs to have the following characteristics (Weisel and Moya 2007):

1) Transparent – to provide an understanding of the assumptions, decisions, and activities that went into V&V (I know what I have)

2) Traceable – to ensure the flow of activities and actions is logical and that appropriate referents for those activities can be located and consulted (I know where I got it)

3) Reproducible – to provide for the event that the same model/data/users will be applied to a similar effort in the future (Another researcher can get the same)

4) Communicable – to produce sufficient, understandable documentation so the effort can be independently duplicated, and so the consumer can make an informed, and perhaps qualified, decision (It is understandable to those who care)

Other objectives include the ability of the process to do the following:

1) Describe the bounds of use for the specified purpose

2) Communicate the risk of use for the specified purpose

The necessary information when communicating the results of validation activities includes, but is not limited to, data sources; referent sources and descriptions; designs of experiments; data and metadata for the model; initial conditions; boundary conditions; parameters; assumptions; analyses performed and methodologies followed; and appropriate uses of results.

The primary purpose, and importance, of conducting validation activities is to assess the risk of using an M&S for a specific application of use. The validation process culminates in the communication of that risk to model and simulation users and the recipients of their data. This includes determining that the simulation is correct and meets requirements through software engineering and other processes but is not limited to that. It also includes providing users with sufficient information to determine if the simulation can meet their needs as well as determining the simulation's capabilities, limitations, and performance relative to the real-world objects it simulates.

3.3 The validation of HBR models

The validation literature consists mainly of validation approaches, paradigms, and techniques as well as specific validation applications and assessments. There is no mechanism guiding the appropriate selection of approach and techniques in a given M&S application. Further, in the physical sciences the concept of valid models is well-understood; this is not the case in HBR modeling. In particular, these models have inherent validation difficulties due to the characteristics of these models (referents that have poor computational underpinnings, complexity, chaotic effects, etc.) and to their desired uses (e.g., Course of Action (COA) Analysis). Techniques for validation will require methods grounded in the larger validation, computational sciences, and experimental design literature and apply them to the growing field of HBR model validation. Any technique applied in this domain will require an assessment of the chosen conceptual model, its implementation in codes, and the subsequent simulation results once used.

3.4 Conceptual model validation

The conceptual model is the representation of the content and concept for the model that includes the logic, algorithms, assumptions, and limitations (Department of Defense 1998). Verification ensures that the code correctly captures this conceptualization. In validation, the conceptual model is compared against the specified referent. In particular, the conceptual model must be true to within the limits of acceptability criteria in terms of the true statements within the referent. While there may be things that are true in the referent that are not true in the conceptual model, the obverse should not occur. That is, *not true* in the conceptual model does not necessarily imply *not true* in the real system that the referent represents. However, there may be things that are true in the real system and in the referent for that system that are not true in the conceptual model because those items purposely were neglected or abstracted out.

While initial assessments may find the conceptual model to be valid, the simulation may produce invalid results nevertheless. This may result from elements initially deemed not important in the model development, incorrect relationships between elements, inappropriate abstraction for the intended use, or poor assumptions. This may especially be true in systems where the conceptual model reflects a referent based in underlying theories of the system without a strong mathematical, analytical, or logical description that translates itself more easily into code. This is partly because programmers can only code those relationships they understand and in part due to the fact that there are many ways to describe desired relationships computationally. For instance, just as there are many possible rule sets for describing a single agent system, there are multiple ways to model the relationship *y* increases with *x*. Results validation may uncover needed changes in the specification of the conceptual model thereby uncovering an invalid conceptual heretofore thought of as valid.

The testing of assumptions made in the model may also uncover previously undiscovered defects in the M&S. These assumptions could include seemingly inconsequential assumptions made during coding efforts such as the precision used for π or the simulation time step or more obviously important assumptions like whether the earth is flat or spherical or the selected social theory. Documentation for every assumption used in developing and coding a model is rarely complete. However, assumptions' testing does not require the explicit identification of every assumption. Only those assumptions potentially affecting the use of the M&S need assessment for their impact. Part of the art in devising the validation analysis assessing a model's assumptions is in recognizing the types of assumptions that might be significant on its use given a description of the model and the context of its specific use and devising tests to assess the impact of the assumptions made. Tests might include sensitivity analyses about the assumptions, accuracy assessments to ensure that the chosen precision is sufficient, or any other appropriate test. Thus, one cannot decouple the results validation from validation of the conceptual model.

3.5 Results validation

Results validation is only meaningful in the context of specific identification of what constitute valid results. This is stressed both in the *VV&A RPG* and by Harmon and Youngblood in the importance of stating the acceptability and validation criteria up front; i.e., the necessary elements for using and trusting the M&S. That is, stating up front the necessary elements for using the M&S. This is equivalent in the validation theory of describing the natural system or referent trajectories against which M&S trajectories will be compared and the validity relation that will be used to make the comparison. It could include statistical comparisons of simulation output to assess the real world match. Often this is an accuracy specification required to support the intended use of the M&S. Engineering models (e.g., for system design and development or for test and evaluation) require predictive accuracy most likely assessed using a metric relation. On the other hand, campaign models may only require sufficient accuracy to enable relative comparisons between alternative outcomes based on changes to tactics, forces, or equipment. Necessary to this assessment is the determination of the simulation results to be measured, the material in the referent against which these results are compared, the mechanism of comparison, and the requirements of the results' acceptability. Results validation could run the gambit from a state-by-state match to observed or empirical data or with some theoretical or posited expectation to an assessment that the overall trends occurring in the model match the theory. In the absence of this specification, the validator, users, and subject matter experts will make their own implicit assumptions of what is required.

Comparing simulation results to empirical or observed data is preferable. While a metric relation could be used to assess accuracy (i.e., the delta between values), other accuracy measurements are possible (e.g., comparisons of direction, slope, or relative magnitude). When this kind of data is not explicitly available, the validator still needs to assess whether the simulation output meets the needs of the intended use (e.g., can help answer the analytical questions). In this case, results validation relies on robust test cases and specification of expected results within the referent determined either from theory or SME opinion.

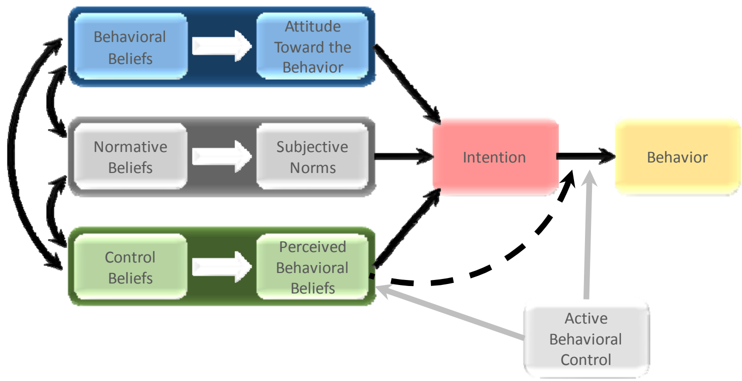
4. CGM Overview

The CGM is a government-owned, open source, data driven multi-agent social simulation. Actors, rules, and laws within the model are built upon social and behavioral science theories. A modular framework is used to allow the incorporation of other social theories or the use of different applications as the CGM grows in maturity. The current implementation of the model uses the narrative paradigm, theory of planned behavior, and Implementation of Entity Cognition with Bayesian Belief Networks (BBN) to determine entity states.

4.1 Narrative paradigm

The use of the CGM requires understanding of the culture in which the scenarios of interest take place. Within the model, cultural beliefs of the entities drive reactions to events occurring within the scenario along with social interactions between entities. To provide a basis for the connection between cultural factors, entity beliefs, and activities, narrative theory plays a critical role in the development of data in the model. In narrative theory, people are storytellers and view the world through a

Figure 3.1: Theory of Planned Behavior, By: Icek Aizen, 2006 (adapted)



narrative lens, thus irrational actions may actually be rational given their history and culture. Its selection was based on Fisher's argument (Fisher, 1988) as follows:

1) people are essentially storytellers;

2) reasons for decisions include history, culture, and perceptions about the status and character of the other people involved (all of which may be subjective and incompletely understood);

3) narrative rationality is based on the probability, coherence and fidelity of the stories that underpin the immediate decisions to be made; and

4) the world is a set of stories from which each individual chooses the ones that match his or her values and beliefs.

Selection of stories for use in data development follow Fisher's proposal of evaluating stories based on whether the narrative's coherence, probability, and fidelity. Narrative coherence means the story should make sense structurally, have detail and characters, and should be free of surprise. Narrative probability concerns the belief of listeners in the truthfulness of the story irrespective of the story's actual truthfulness. Narrative fidelity addresses the truthfulness of a story with respect to cultural values that include embedded values, relevance between the story and the values espoused, consequences, consistency, and transcendence.

4.2 Theory of planned behavior

The theory of planned behavior provides the underlying basis for the development of data for entity intention, action, choice, and selection within the CGM. In the theory of planned behavior (Figure 3.1)[1], entities form behavioral intentions based on attitudes, perception of group norms, and perceived level of control.

4.3 CGM Conceptual Model

To Be Added in final paper – Provide a description of the CGM mathematical and logical implementation guiding the direction for the validation effort.

5. Challenges

The problems we face in the current warfare environment make the development of HBR models sufficient to address the problems of interest and their validation importance. Having useful, credible, robust information is critical for the support of sound decision-making. However, limitations in the current state of the art create challenges. First, the systems of interest are complex. One of the reasons for developing the models is to develop an understanding of the systems' behavior in response to various scenarios that might occur. That is, we want to understand the system of interest. However, the social science that forms the underpinning of these models often has multiple, conflicting theories for behavior, complicated by variances in responses by culture and stressor. This creates difficulty in model development and acceptability. That is, our understanding of the system is limited.

[1] Copyright Notice: The theory of planned behavior is in the public domain. No permission is needed to use the theory in research, to construct a TpB questionnaire, or to include an original drawing of the model in a thesis, dissertation, presentation, poster, article, or book. However, if you would like to reproduce a published drawing of the model, you need to get permission from the publisher who holds the copyright. You may use the drawing on this website for non-commercial purposes so long as you retain the copyright notice. – To Be Redrawn

Second, the systems of interest are dynamic. The development and testing of models requires data to support them. Further, these models also require data related to the relationships between elements or entities within the model. This includes influence relationships between elements as well as cause-effect relationships. Not only is obtaining this data difficult, especially for the problems of interest, the data developed is often qualitative vice quantitative and has an unknown valid lifetime. In particular, it is unknown whether the data valid lifetime exceeds the initial stressor events of interest.

The third challenge is a direct result of the first two. Since these M&S exist in a computer, necessary to the model development is a computational representation of the social theories, interactions, and behaviors of interest. While there are some accepted representations such as Bayesian networks, this is far different from the general acceptance found in the computational representations found in the physical sciences. To create valid models, both conceptual model and results validation is required. The validation of either requires progress in both the social sciences to develop accepted computational representations as well as measureable system responses to events or inputs to the system.

6. Next Steps

The objective of this project is a repeatable approach for validating cultural behavior models, particularly the conceptual model, including risk measures and criteria for assessing risk using the CGM as a vehicle for the method's implementation. While there are many challenges in HBR modeling, making progress in techniques for the M&S of HBR and in developing methods validating those M&S is necessary. The next steps in this project are to continue evaluation of the CGM conceptual model. Critical to the effective use of M&S is the understanding of the risk in that use for a specific problem of interest. This is the key goal for validation. The understanding of the risk in using a simulation for a specified use is a core area of research for this work.

There are two components of risk in general (Defense Acquisition University 2003):

1. The probability or likelihood of achieving (not achieving) a given outcome

2. The consequences of achieving (not achieving) a given outcome

There is higher risk with a higher likelihood or with significant consequences. Risk assessment includes both the identification of risk (determination of outcomes) and the analysis of risk (determination of probability and consequence of an outcome). It is in this latter aspect that M&S often plays a role. That is, the intended use for an M&S is to identify and help to mitigate risk, identified as part of some specified objective. However, the use of M&S in this analysis poses an inherent source of risk. The sources of risk could lie in the development of the model, development risk, or in the running of the simulation, operational risk (Modeling and Simulation Coordination Office 2004b). Development risk is that the model does not meet the requirements for its intended use. Operational risk is that the M&S exhibits insufficient accuracy to provided needed information. The V&V process addresses both these risk areas. When considering intended use, risk can be described generally using the three familiar error types:

1. Type I Error: Reject correct information; the information provided by the M&S is not used in solving the problem even though the information provided is correct.

2. Type II Error: Accept incorrect information; the information provided by the M&S is used in solving the problem, however, the information provided is incorrect.

3. Type III Error: Solve the wrong problem; the information provided by the M&S is irrelevant to the actual problem to be solved.

Validation primarily assesses the Type II error. When assessing the consequences of using incorrect data in a decision, considerations include who is affected, the severity of the effect, and the visibility of the consequences. Development risk assesses the effect of not meeting requirements, the likelihood of a deficiency, and the probability that a deficiency will cause the M&S not to meet requirements. These assessments drive toward the fundamental assessment of whether the M&S support the intended use. Operational risk assesses the probability of making an incorrect decision, the effect and visibility of making an incorrect decision, and specific user considerations.

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