i. **Cover Page**

A System Dynamics (SD) Approach to Modeling and Understanding Terrorist Networks

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BAA-07-01-IFKA
Proactive Intelligence (PAINT): Model Development

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D&B D-U-N-S Number 00-142-5594
Commercial and Government Entity (CAGE) code #: 80230

Total Period of Performance: 54 months

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iv. **Executive Summary**

The Proactive Intelligence (PAINT) program has four stated goals:

1) To develop predictive models of current or emergent situations that may threaten the US. These models should span the entire life-cycle of situations and should be inclusive of the environmental context.

2) To identify factors and strategies that may influence the evolution of these threats.

3) To develop methods for determining comprehensive indicators of these threats.

4) To use real world data and key indicators as feedback to adjust the models, their predictions, and potential influence strategies in goals 1-3.

Many approaches to analyzing terrorist networks are based on “driving forward by looking through the rear-view mirror.” That is, they rely almost exclusively upon the use of past data to predict the future. Although this sometimes is helpful, they frequently can lead to very wrong predictions, especially when the actual outcome is counter-intuitive, and, furthermore, they often provide little insight and understanding of the reasoning.

In contrast, the System Dynamics (SD) approach is based on identifying individual causalities and how they combine to create, often non-linear, feedback loops that are the causes of the counter-intuitive outcomes. This approach can greatly leverage the deep, but often isolated and fragmented, knowledge of terrorism from Subject Matter Experts to provide much better insights and understanding of terrorist networks and how to develop effective counter-measures.

System Dynamics is an approach for modeling and simulating complex physical and social systems, and experimenting with the models to design policies for management and change. The core of the SD modeling strategy is representation of system structure in terms of stocks, flows, and the causal mechanisms that govern their rates of change. In this connection, feedback loops are the building blocks for articulating the causality represented in these models. The interaction among the various feedback loops in a model can represent and explain system behavior.

SD models offers unique capabilities to the understanding of terrorist networks and their impact. SD explicitly recognizes the complex interactions among many feedback loops, rejects notions of linear unidirectional cause-and-effect, and allows the analyst to view a complete system of relationships whereby the ‘cause’ might also be affected by the ‘effect’. SD enables analysts to uncover ‘hidden’ dynamics. It also allows for understanding the long term effects of short term policies or behaviors.

Additional unique capabilities of SD include:

- *Objective input*: Ability to utilize data to determine, with precision, parameters affecting the causality of individual cause-and-effect relationships.
- *Subjective (expert) judgment*: Ability to represent and model cause-and-effect relationships, based on expert judgment, even when detailed data does not exist.
- *Intentions Analysis*: Ability to identify the long-term unintended consequences of policy choices or actions taken in the short term
- *Tipping point analysis*: Ability to identify and analyze “tipping points” – where further incremental changes lead to significant impacts.
- *Transparency*: Ability to explain the reasoning behind predictions and outputs of the SD model.

- *Modularity*: Ability to organize SD models into collections of communicating sub-models (e.g., terrorism recruitment, economic development, religious intensity, regime stability)
- *Scalability*: Ability to use the modularity to increase complexity without becoming unmanageable.
- *Portability*: Ability to utilize the same basic SD model in different regions of the world without requiring re-formulation.
- *Focusable*: Ability to increase details in specific areas of the SD model to address specific (and possibly new) issues.

We propose to demonstrate the capability of using SD modeling methodology to meet PAINT's four goals by answering the following Grand Challenge question:

How should the Government analyze terrorist networks in the context of the political, religious, social and economic networks that intersect with, influence, and are influenced by, the terrorist network; predict the formation, evolution, vulnerabilities, and dissolution of the network; and identify strategies to shape or influence the network through selective action?

The approach and analysis of the SD model development will demonstrate its creativity and innovation and its ability for: (a) rapid implementation and modification, (b) comprehensive ability to describe, explain, and support predictions of specified threatening situations – this is an area where the "transparency" of SD models is critically important, (c) the integration with other models, and (d) model validation.

In addition, SD modeling can incorporate an understanding of how structure and decision policies help generate predictions along with the management changes implicit in addressing system outcomes. The proposed SD model will allow end-users to focus on identifying high-leverage policy interventions and plan for the implementation of robust decision policies across a range of activities, while building an intuition about overall system behavior.

The MIT team has had extensive experience in the use of System Dynamics modeling in areas ranging from management of software projects to work for CIA and DIA on Security in Central Asia. Of particular relevance to PAINT is the recent work done in developing State Stability Models for DARPA's Pre-Conflict Analysis and Shaping (PCAS) effort including the exploration of the use of these results in analyzing PACOM's Theater Security Cooperation (TSC) Planning and the impact of various Diplomatic, Intelligence, Military, Economic, Financial, Informational and Law Enforcement (DIMEFIL) actions.

In addition, National Security Innovations (NSI), Inc. is proposed as a subcontractor. NSI specializes in providing innovative yet pragmatic scientific, technical, analytical, and programmatic services and technologies to complex 21st century national security problems by leveraging quantitative and computational modeling and analytical methods with principles from the social and physical sciences.

MIT proposes to use the System Dynamics methodology, its experience with SD, and the assistance of NSI to accomplish the four goals of PAINT and aid in the transfer of this capability to the appropriate government agencies.

1.0 <u>Technical Approach</u>

1.1 <u>Technical Discussion</u>

Many approaches to analyzing terrorist networks are based on "driving forward by looking through the rear-view mirror." That is, they rely almost exclusively upon the use of past data to predict the future. Although this sometimes is helpful, they frequently can lead to very wrong predictions, especially when the actual outcome is counter-intuitive, and they provide little insight and understanding of the reasoning.

In contrast, the System Dynamics (SD) approach is based on identifying individual causalities and how they combine to create, often non-linear, feedback loops that are the causes of the counter-intuitive outcomes.

This approach can greatly leverage the deep, but often isolated and fragmented, knowledge of terrorism Subject Matter Experts to provide much better insights and understanding of terrorist networks and how to develop effective counter-measures.

1.1.1 <u>PAINT area addressed: Model Development</u>

We propose to demonstrate the capability of using System Dynamics (SD) modeling methodology to meet the four goals of this BAA by answering the following important Grand Challenge question:

> *How should the Government analyze terrorist networks in the context of the political, religious, social and economic networks that intersect with, influence, and are influenced by, the terrorist network; predict the formation, evolution, vulnerabilities, and dissolution of the network; and identify strategies to shape or influence the network through selective action?*

Understanding the nature of these relationships is rooted in knowing how an organization or a country functions and the principles that guide that functionality. Terrorist networks demand our attention today because of the apparent ease with which they inflict damage around the world. The increased impact has partially arisen by the availability of the technology that allows a hostile group global access – this enables the terrorist organization to accelerate its learning cycle and magnify its "messaging" ability. Modeling and understanding the problems created by these new capabilities is a central focus of our proposed efforts.

1.1.2 <u>Project Background</u>

Understanding the growth of terrorist networks is an essential part of the Global War on Terrorism (GWOT). Applying System Dynamics (SD) modeling techniques can provide tremendous insights into the behaviors of terrorist groups that threaten regional stability and, by extension, national security. These inputs can directly affect the efficiency by which the U.S. and its allies deal with terrorist networks. We propose to develop a SD model which will provide insights for understanding and mitigating terrorist growth and activity.

1.1.2.1 Prior Work

There are a number of areas of prior work by this team that relate to the proposed research. These are the use of System Dynamics as a modeling tool, the recent development of State Stability Models for DARPA's Pre-Conflict Analysis and Shaping (PCAS) effort including the use of these results in PACOM's Theater Security Cooperation (TSC) Planning, the earlier work for CIA and DIA on Security in Central Asia, and the set of modeling and simulation studies on conflict and violence in international relations focusing on competition among major powers.

1.1.2.2 System Dynamics Modeling

System Dynamics (SD) is an approach for modeling and simulating (via computer) complex physical and social systems, and experimenting with the models to design policies for management and change (Forrester, 1980; Forrester, 1991). The core of the modeling strategy is representation of system structure in terms of *stocks, flows, and the causal mechanisms that govern their rates of change*. In this connection, *feedback* loops are the building blocks for articulating the causality represented in these models. The interaction among the various feedback loops in a model can represent and explain system behavior.

System Dynamics Modeling (SDM) has been used for a wide range of purposes, such as to capture the dynamic relationship of energy and the economy, to model the world petroleum market over a period of thirty decades, to explore dynamics of economic growth, to analyze the environmental implications of international trade, to understand supply-chain management, to analyze different policies for nation-building, to model software development, and to examine the intricacies of the air force command and control systems.

SDM offers unique capabilities to contribute to social science, economics, or political science modes of analysis – all of which are relevant to understanding terrorist networks. SDM recognizes the complex interactions among many feedback loops, rejects notions of linear cause-and-effect, and allows the analyst to view a complete system of relationships whereby the 'cause' might also be affected by the 'effect'. SDM enables analysts to uncover 'hidden' dynamics. It also allows for understanding the longer term effects of short term policies or behaviors. Thus, inter-temporal features of 'causes' and 'consequences' can be better understood. Moreover, SDM allows the analyst an increased level of flexibility as SDM utilizes both conceptual understanding as well as empirical data collection. By understanding the dynamics of a state system, including interactions among actors, actions, structures and processes in complex environments, one can better identify how to reinforce state capabilities while diminishing the loads and pressures exerted upon it.

1.1.2.3 Example of System Dynamics Modeling Applied to Examining State Stability

Most recently the MIT Team developed a general SD model and analysis for the Pre-Conflict Analysis and Shaping (PCAS) program at DARPA (Choucri et al, 2006). In this work we modeled (and 'predicted') how and when threats to stability tend to override the resilience of the state and to undermine its overall capabilities and performance. The loads in the system were represented by dissidents, insurgents, their activities and messaging capabilities.

In the model, the state is stable to the extent that the loads or pressures upon it can be managed by its prevailing capabilities or performance capacities. More specifically, we isolated the 'tipping points' – conditions under which incremental changes in anti-regime activity can generate major disruptions – and then sought to identify appropriate actionable mitigation factors to reduce the potential for 'tipping' and enhance prospects for stability.

The model shows the sources and consequences of insurgent recruiting, constrained and limited by the resilience of the regime and the extent to which the state can manage anti-regime activities. To simplify, of the many actions that insurgents choose to perform in order to undermine regime legitimacy, we modeled those associated with stimulating, producing and circulating anti-regime communications, an area where terrorist networks have been effectively exploiting new technologies. Anti-regime messaging and communication are thus major mechanisms for increasing insurgent recruitment and for mobilizing opponents to the regime. The context in which these activities occur is partly shaped by the regime. The state's capacities and the resilience of the regime operate such as to counter insurgency recruitment. Figure 1 below shows the conceptual structure of our Insurgent Recruitment Model.

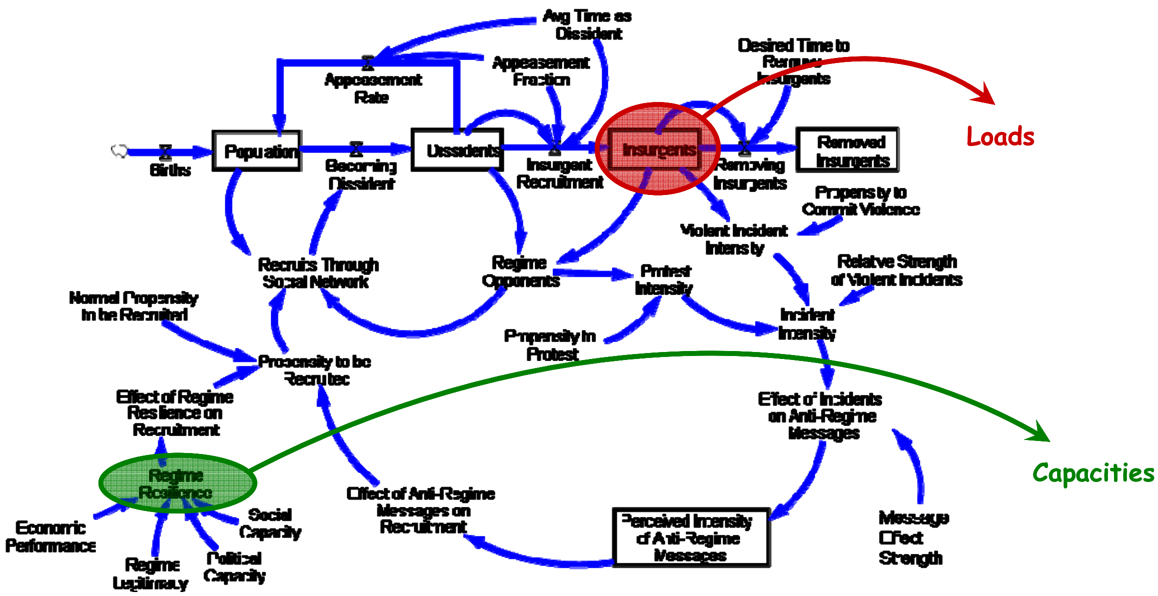

Figure 1: Conceptual Model of Insurgent Activity and Recruitment (Simplified)

The logic of the model can account for many known patterns of insurgent recruiting. The model was developed drawing upon the social science literature and earlier studies in the computational social sciences as well as interviews with experts in the field. Indeed, every link is the model was 'validated' by evidence from the literature and Subject Matter Experts (SMEs).

1.1.2.3.1 *Insurgent -Process*

Whereas Figure 1 presents a high-level view of the dynamic interactions, it can be further analyzed at a more detailed level. The model is developed as a set of stocks and flows, each of which is explicitly represented in algebraic form. For example, Figure 2 shows the stock and flow diagram for insurgent recruitment. It shows that in any given state with a given number of people, there are some peaceful anti-regime elements (dissidents) and there are some violent anti-regime elements (insurgents). Thus, we divided the population into three stocks, labeled Population, Dissidents, and Insurgents, and (shown as rectangles in Figure 2). The model shows transitions from one stock to the other, with icons resembling pipes and valves. The basic logic is this: People in the general population may become dissidents and after some time these dissidents may become insurgents. This process is not automatic, since it takes into account a set of intervening contingencies. There are two direct ways to achieve a lower number of insurgents, however. First, dissidents might become appeased by the state and return to the general population, thus reducing the number of dissidents and curbing the transition to insurgents. A peaceful regime change or a policy change may placate these dissidents into regime supporters. Second, dissidents who become insurgents can be removed from the system by the state. This could occur through arrests, detentions, or state violence. These approaches to reduce dissidents and insurgents, respectively, are shown as the "Appeasement Rate" and "Removing Insurgents" in Figure 2.

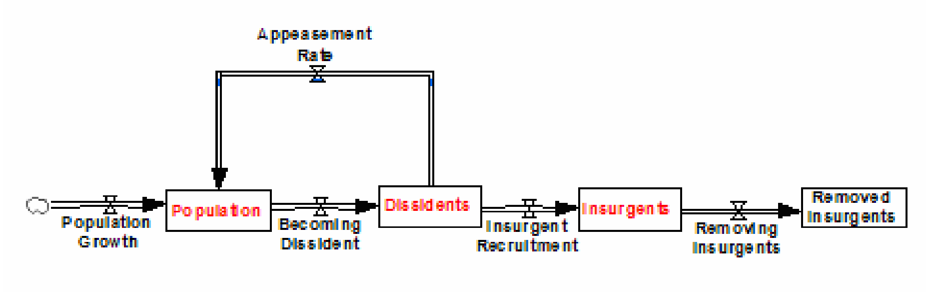

Figure 2: Population-to-Insurgent Flow

The advantage of this modeling logic is that it allowed us to locate and track the insurgency process and identify alternative intervention points. However, there are notable other conditions affecting the Population-to-Insurgent flows. There are several different elements that can affect the transition of a normal member of society to a dissident to an insurgent. Figure 3 introduces the next level of complexity. For example, when considering the component of removing insurgents, it is important to also consider the removal effectiveness, the indicated force strength, and the desired time to remove insurgents in order to assess how well insurgents are removed. Even though several of these variables are exogenous to this model, they can nonetheless be affected by different policy levers that will affect the overall system.

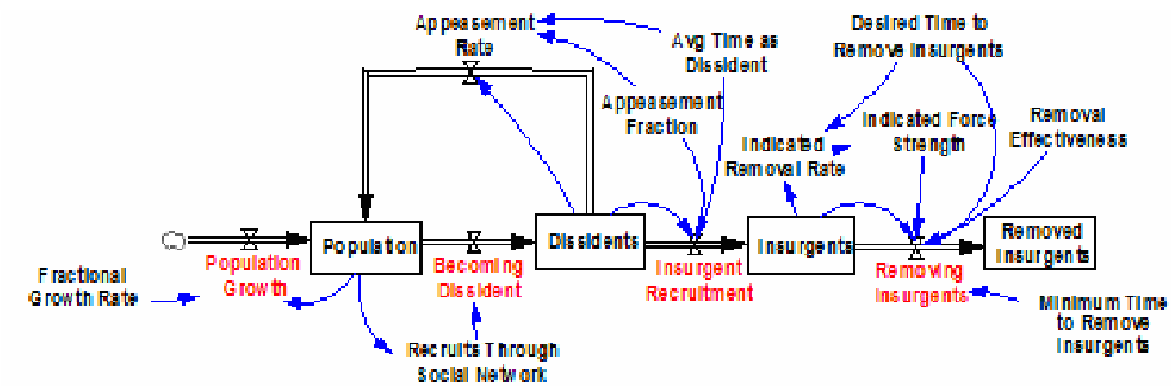

Figure 3: Other Ways to Affect the Population-to-Insurgent Flow

We took the model further as shown in Figure 1 and developed an operable model and applied it to two distinct regions in Southeast Asia. For example, one way to increase the regime voice is to sponsor a public campaign against the insurgents (to undermine their legitimacy). As recently observed in Jordan in November 2005, as a result of extreme terrorist acts by Al Qaeda, the state was able to garner public sentiment. That can become a very successful method for controlling anti-regime elements. There are many ways that states can increase the regime voice to counter the threats. Figure 4 compares the results of changes in each of such inputs.

1.1.2.3.2 *Compare Policy Alternatives*

Using the model, we were able to compare different policy alternatives, as shown in Figure 4. The upper line (in blue) shows the projected growth in insurgents if no action is taken. In this experiment, we considered two policy prescriptions:

(1) the state might become better at removing insurgents (shown in red), or

(2) the state might improve its ability to respond to anti-regime messages, dampening the message strength (shown in green.)

These policies lead to different levels of impact. The first option delays the growth of insurgents, but does not eliminate it. The second option leads to a reduction in insurgents.

In either case, it is important to track and understand the long term effects of policy prescription, since 'exporting' the problem into the future is quite different than actually managing or controlling its threats to stability.

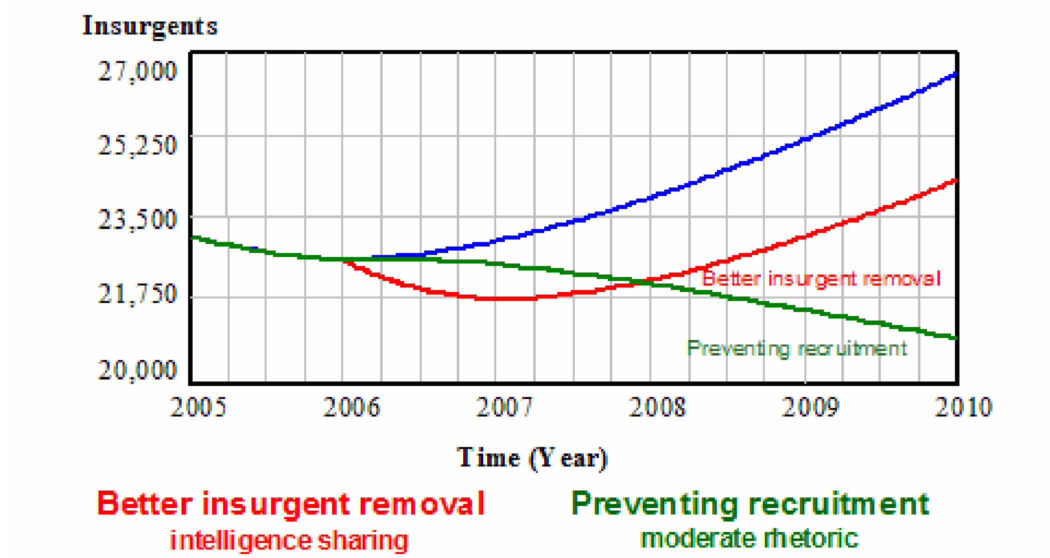

Figure 4: The Potential Effects of Increased Removal Effectiveness (Intelligence Sharing) versus Weakening the Message Strength (Moderate Rhetoric)

The above example looks at the ability for terrorist groups to recruit and use their operations and messaging capability to affect a regime. Another example of operational capacity of terrorist networks may include fundamental issues about how such networks learn and adapt to new techniques as presented by the US and its partners. A simple view of this can be seen in the casual diagram in Figure 5.

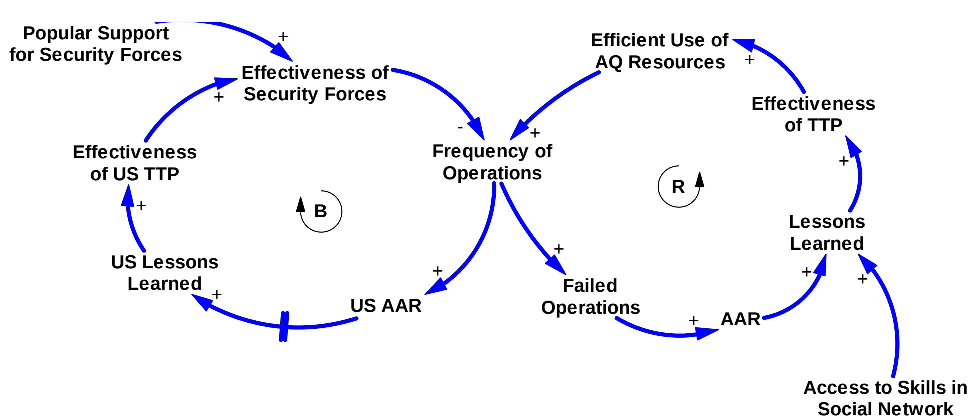

Figure 5: Relationship between learning in Terrorist Networks and Learning in Security Forces

From this diagram we see that both sides learn from operations, however there is significant evidence that learning takes place at different rates and as a result can on occasion place the terrorist networks at an advantage. Studying these phenomena can provide insight into ways to effect terrorist networks through reducing their ability to learn and efforts to increase our ability to learn faster.

1.1.3 Metrics, Validation, and Prediction

There are various ways that can be used to measure and validate System Dynamics models and then use the model to perform predications and analysis. We plan to use all of these methods. Forrester and Senge published a seminal paper on the testing of system dynamics models (Forrester, 1980) that described a battery of specific tests for building confidence in system dynamics models. These tests were grouped into tests of model structure, tests of model behavior, and tests of policy implications. The latter include such tests as formal inspections, walkthroughs, and semantic analysis. Behavior tests include extreme conditions tests, behavior sensitivity tests, modified behavior prediction, boundary adequacy, phase relationship test, qualitative features analysis, and the Turing test. Sterman relied heavily on these prior works when he wrote the chapter on model testing in his now classic textbook on business dynamics. The model tests recommended by Sterman (Sterman, 2000, pp 859-861) are as follows:

1. Boundary Adequacy: Does the selection of what is endogenous, exogenous, and excluded make sense?
2. Structure Assessment: Is the level of aggregation correct, and does the structure conform to reality?
3. Dimensional Consistency: Do the units of the model make sense, and does the model avoid the use of arbitrary scaling factors?
4. Parameter Assessment: Do the parameters have real life meanings, and are their values properly estimated?
5. Extreme Conditions: Do extreme parameter values lead to irrational behavior?
6. Integration Error: Does the behavior change when the integration method or time step are changed?
7. Behavioral Reproduction: How well does the model behavior match the historical behavior of the real system?
8. Behavior Anomaly: Does changing the loop structure lead to anomalous behavior consistent with the changes?
9. Family Member: How well does the model “scale” to other members within the same class of systems?
10. Surprise Behavior: What is revealed when model behavior does not match expectations?
11. Sensitivity Analysis: Do conclusions change in important ways when assumptions are varied over their plausible range? Changes in conclusions could be numerical changes, behavior mode changes, or policy changes.
12. System Improvement: Does the model generate insights that actually lead to the hoped for improvements?

1.1.4 Model Complexity Management

It is wise advice that "a model should be as simple as possible and only as complex as needed." Thus, unneeded complexity will be avoided in this project. In addition to that strategy, there are methods for managing the increase in SD model complexity that might be needed to satisfy the model's requirements.

The primary method is the use of SD model subsystems (which can be further decomposed into sub-subsystems, if needed.) Our current plan is divide our High Level Model (HLM) into at least three major subsystems:

(a) *regime resilience*
(b) *government capacity,* and
(c) *terrorist network activities and growth.*

Each of these subsystems have internal dynamics as well as dynamic interactions with the other subsystems. This multi-level layer approach greatly simplifies the complexity both in model development and refinements as well as model usage and understanding. This technique has been used very effectively in many SD modeling projects.

1.2 **Technical Program Summary**

Terrorist networks demand our attention today because of the apparent ease with which they inflict damage around the world. The increased impact has partially arisen by the availability of the technology that allows a hostile group global access – this enables the terrorist organization to accelerate its learning cycle and magnify its "messaging" ability. Modeling and understanding the problems created by these new capabilities is a central focus of our proposed efforts. Understanding the nature of these relationships is rooted in knowing how an organization or a country functions and the principles that guide that functionality.

This technical program shall address the dynamics of the terrorist network (including interactions among actors, actions, structures and processes in complex internal and external environments) seeking to manage its pressures given its capacities, while diminishing the loads and pressures exerted upon it. We propose to focus on, and model, three sets of dynamics processes: (a) the state and regime, (b) the capacities of government; (c) sources and manifestations of terrorism – and the interactions among them in order to capture the propensities for overt terrorism.

The tasks in each Phase of the technical program are defined by increasing complexity along multiple dimensions: (1) increasing sophistication of the System Dynamics model, (2) increasing complexity of challenge problem, (3) data that tends increasingly towards near real-time, real-world data, (4) increasing speed of development and adaptability of dynamic simulation and gaming models, and (5) increasing complex user-model interactions. The High Level (HLM) System Dynamics model to be developed is envisioned of consisting of three major sub-systems (each with sub-modules or sub-systems as needed) to represent the dynamics of: (a) *regime resilience,* (b) *government capacity,* and (c) *terrorist network activities and growth.* These sub-systems will be developed, improved, validated, and utilized to predict and analyze possible actions over the course of this technical program.

1.3 **Risk Analysis and Alternatives**

Every technology, such as a modeling methodology, has its limitations and shortcomings. A good overview report comparing different modeling approaches applied to security issues, including System Dynamics, can be found in the report by Axelrod (Axelrod, 2004) funded by the CIA. The immediately following material comes directly that report (with minor editing.)

Goal: While central Asia is important in its own right, the main goal of that modeling effort was to test the value of modeling for a wide range of topics of interest to intelligence analysts. From this perspective, central Asia is merely an example. *The main point is to learn lessons about the kind of help that modeling can provide to analysts*. Contributing to these lessons is the reason for this report.

Lessons Learned about System Dynamics modeling: A major advantage of using a system dynamics diagram is that it provides a useful way of representing beliefs. Because the diagram idea of system dynamics can be taught in less than an hour, typical users could construct and use such diagrams for themselves. A user begins with a few variables of interest, such as "extremist power" and "defensive investment" and then writing down the causes and effects of these variables. This is done in terms of signed arrows to and from these original variables, adding new variables as necessary. Then the user is then invited to think about the causes and effects of these new variables, and write down additional variables and causal links between them. The user needs to exercise a certain degree of restraint by discarding ideas that go off in entirely different directions, and sticking to variables and causal pathways that might eventually lead back to the original items of focal interest, such as "extremist power" and "defensive investment."

Once the user has represented his or her ideas as points (variables) and arrows (causal links between variables), the resulting graph is likely to reveal some relationships that the user may not have previously considered. In Saeed's example, there is not only a negative feedback loop from defensive investment to extremist power going through reduced threats to the government, there is also a positive feedback loop between defensive investment to extremist power going through reduced economic investment.

Asking a user to represent his or her beliefs in the form of a graph of points and arrows can be helpful in several different ways:

1. By formulating his or her beliefs in a structured and visual manner, the analyst may well come to see some relationships that were not obvious before. Using Saeed's example, the analyst who was well aware of one of these feedback loops might see that there was a competing feedback loop that he or she had not taken into account. The analyst might then start to think about which of the two causal pathways will dominate in determining whether defensive investment will increase or decrease extremist power in some particular setting.

2. Thinking about what is needed to answer such questions that arise from the diagram might lead to new intelligence requirements.

3. Several analysts could work together to develop a single graph. This exercise could help the analysts identify their differences, and see which of these differences represent some factor that one analyst had not even considered, and which differences represent differences of beliefs worthy of discussion.

4. A cognitive map can be a useful way to communicate a complex set of beliefs in visual terms. As Saeed's example shows, even 14 variables and 21 causal mechanisms can be encompassed in a single cognitive map that is easy to visualize and analyze.

The comparison with other modeling methodologies is summarized in the adaption of Axelrod's Table I below.

Table I
(adapted from Axelrod, 2004)
Appropriateness of Modeling Methodologies:
Low, Medium or High on Six Criteria

	Construction time	User Pre-requisites	Learning Time	Flexibility	Repertory size	Transparency
Game Theory	L	L-H	L-H	M	H	L-H
Agent-Based Modeling with Light Agents	M	L	L	M	M	H
Agent Based Modeling with Heavy Agents	H	M	M	H	L	M
Dynamical Systems	M	H	H	M	M	M
System Dynamics	**L**	**L**	**L**	**H**	**L**	**H**
Data-driven Models	M*	M	L	M*	M	H

Note: Ideally, **first three criteria should be Low**, and the **last three criteria should be High**.

*Excluding construction or expansion of the database.

The Criteria

Construction Time. Time and effort needed for a modeler skilled in this methodology to build a useful model with input from users.

User Prerequisites. Amount of technical background needed by the user to understand as well as use the model.

Learning Time. Time and effort for a typical user with the necessary prerequisites needs to learn a specific model.

Flexibility. Ease with which the modeler can modify the model to incorporate a new variable.

Repertory size. The number of published models of this type with features that could be adapted for use as part of a model on issues relevant to security in central Asia.

Transparency. The ease with which the user can discover anything in the model that might bias the results.

In terms of "risk analysis," the System Dynamics methodology rates very well on five of the six criteria identified in Table I. The one area of potential concern is Repertory size: The number of published models of this type with features that could be adapted for use as part of a model on issues relevant to terrorist networks (the focus of this proposal.) We plan to address this risk in several ways:

- The number of such models has been increasing through efforts such as PCAS. We plan to draw on the results of these other efforts.
- We have identified sources of literature and data that will assist us in developing new models (actually usually sub-models) appropriate for this project.
- We have established relationships with Subject Matter Experts (SMEs) in academia, industry, and government that can assist us in developing new sub-models (or refining existing models) appropriate for this project. This is the one the areas in which the subcontractors. NSI, Inc., will be very valuable.

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2.0. Special Technical Factors

2.1 Capabilities and Relevant Experience

2.1.1 **System Dynamics**

We propose to use the System Dynamics (SD) modeling methodology. SD was first introduced at MIT in 1956 by Professor Jay W. Forrester (Forrester, 1958) and, although it is now widely used, MIT remains the key center of SD research and experimentation. The SD discipline combines the theory, methods, and philosophy needed to analyze the behavior of complex systems — in fields such as management, environmental change, politics, economic behavior, medicine, and engineering. Our graduate students study principles of systems, economic and industrial dynamics, and policy analysis, while doing additional work in economics, information systems, statistics, and political science.

2.1.2 **Information Technologies and Political Science**

The Principal Investigators on this proposal have extensive experience in the areas of Information Technologies and Political Science – both as separate fields and at their intersections. In Political Science it is assumed that "knowledge is power" and applications of innovations in information technology facilitate the exercise of "power" and enable analysts to greatly improve their investigations. Our graduate students are exploring such advances in the domains of governance, in uses of the Internet for strategic purposes, in various cyber threats that can undermine political stability, to name only a few cases. The concept of CyberPolitics is recently introduced to cover some of these new issues in the field.

2.1.3 **Dynamic Gaming and Strategies, Key Indicators, Architecture and Integration**

We will work with the other PAINT groups working on the areas of (1) Dynamic Gaming and Strategies, (2) Key Indicators, and (3) Architecture and Integration. We have worked very effectively with some of the other potential PAINT researchers in other initiatives, such as PCAS.

In addition, we have certain expertise in these areas that we will contribute to the overall PAINT effort.

2.1.3.1 Dynamic Gaming and Strategies

System Dynamics has been extensively used by MIT in various dynamic gaming situations, often called "management flight simulators." The very popular "beer game" demonstrates how managerial "instincts" often lead to counter-intuitive and erroneous results. A full analysis of the beer game flight simulator appears in J. Sterman (1989). Other management flight simulators and applications to real organizations are described in (J. Morecroft and J. Sterman, 1994.) We expect to contribute to PAINT initiatives in this area by providing our experience with such "flight simulators" and their visualizations.

2.1.3.2 Key Indicators

We shall be addressing relevant data-issues related to Key Indicators as necessary to accomplish our proposed work and contribute to the overall PAINT effort as needed. We have had experience with identifying and understanding Key indicators in other projects, including uses of statistical techniques, cluster analysis, and pattern recognition methods.

2.1.3.3 Architecture and Integration

Information Technology Architectures, and innovative technologies, to support effective Integration have been major research foci for our group at MIT, with Drs. Madnick and Siegel as PI's, for a considerable time. For example, "Context Interchange: Using Knowledge about Data to Integrate Disparate Sources," was one of the projects under DARPA's Intelligent Integration of Information (I^3) research program during 1992-1998. Since then, these technologies have been improved and tested in various environments, including a 2005 project to facilitate the integration of intelligence data, entitled "Improved Data Access and Interoperation Using Context Mediation," funded through SAIC (Madnick, S., et al, 2005.)

2.2 <u>Previous or Current Relevant IR&D Work and Points of Contact</u>

The PI's on this proposal have been involved in various previous System Dynamics research. A couple examples are summarized below. Additional relevant research is described in section 2.3 below.

2.2.1 **International Energy Futures: Petroleum Prices, Power, Payments,** MIT Press 1982.

Professor Nazli Choucri - NSF Supported

<u>Case</u>: The model develops in modular format (in terms of seven different sectors of actor-driven processes). Parameters for the core sector (oil producers and production) estimated empirically via econometric analysis. Since this was an NSF project, the peer process was extremely lengthy and detailed.

<u>Effort/Time</u>: Basic structure, analysis, and results – 8 months; Writing and documentation for publication, peer review, revision – 2 years.

<u>Value</u>:

Independent audit by Stanford University Energy Modeling Forum subsequently indicated that this was the only model that correctly anticipated future price paths (when compared to the unfolding of history/time). The 'correct' prediction/ forecasts are due to the correct decision of modeling the oil production process in considerable detail. The results ran counter to the dominant views at the time that prices would inevitably skyrocket by 1990. This view turned out to be wrong.

<u>Lessons Learned</u>:

1. Modular modeling strategy is very robust
2. Empirical estimation of parameters must be done strategically (not compulsively)
3. Modeling the critical drivers to decision and choices determines overall system behaviors best
4. Too much detail and complexity in modeling and the modeling structure increases accuracy, but it also increases time and effort.
5. For all practical purposes, this added effort is important largely for theoretical and scholarly purposes, not for policy or practical purposes.

2.2.2 **Lessons Learned from Modeling the Dynamics of Software Development**, *Communications of the ACM*, Vol. 32, No. 12, December 1989, pp. 1426-1438, 1455; also in *Software Project Management: Readings and Cases* (editor C. Kemerer), Irwin, 1997, pp. 144-163 (copy at http://web.mit.edu/smadnick/www/System%20Dynamics%20papers/p1426-abdel-hamid.pdf) and *Software Project Dynamics: An Integrated Approach*, Prentice-Hall, 1991, ISBN 0-13-822040-9, 264 pp. (Received the Jay Wright Forrester Award for "Best Contribution to the field of System Dynamics in the preceding five years" awarded by the System Dynamics Society, 1994.)

Professor Stuart Madnick – partially supported by NASA.

Case: Software systems development has been plagued by cost overruns, late delivery, poor reliability, and user dissatisfaction. This study used the feedback principles of system dynamics to explain and address these issues.

Effort/Time: The initial modeling effort took about 6 months. The model was used over a period of another 6 months to study various different software development issues. Most importantly, the model was parameterized to analyze a project with very different characteristics (the NASA DE-A satellite project) in a very short amount of time – and the model very accurately reproduced some of the unusual and unexpected behavior of this project.

Value: This paper and the book that describes the complete model and experiments performed were widely cited and received a "Best Contribution" award.

Lessons Learned: There were many lesson learned. The paper cited above primarily devoted to describing them. Some examples include:

1. A project is behind schedule. Possible management actions include: revise completion date, hold to planned schedule but hire more staff, hold to planned schedule but work current staff overtime, etc. The implications of each of these options under different circumstances are studied.
2. How much of the development effort should be expended on quality assurance and how does that affect completion time and total cost.
3. What is the impact of different effort distributions among project phases (e.g., should the ratio of effort between development and testing be 80:20 or 60:40)?
4. What is the impact and consequences of assigning staff part-time to a project (increases flexibility) versus only full-time (reduced communications and coordination efforts).
5. Why does the "90% completion syndrome" in software projects chronically recur despite efforts intended to avoid it?

2.3 Related Government Contracts and Points of Contact

The PI's on this PAINT proposal were also the PI's on BAA 04-17 from DARPA's Innovative Information Exploitation Office (see
http://www.darpa.mil/ixo/solicitations/IXO/index.htm)
Pre-Conflict Anticipation and Shaping (PCAS) Program.

Our project was entitled: **Understanding & Modeling State Failure: Exploiting System Dynamics**

The Summary of the project was (with some updating):

In its Preface, The *9/11 Commission Report* states: "We learned that the institutions charted with protecting …national security did not understand how grave this threat can be, and did not adjust their policies, plans, and practices to deter or defeat it" (2004: xvi). Given current realities and uncertainties "better preparedness" can be achieved by identifying, controlling and managing the elusive linkages & situational factors that fuel state decay and destruction – and hence create new threats to the nation's security.

This project focused on the use of system dynamics modeling techniques to develop future anticipatory technologies that help to understand, measure and model the complex dynamics shaping and precipitating state failure, specifically in Indonesia and Thailand.

The 12-month research effort focused on state failure anticipation and analysis. It specifically considered the impacts of unanticipated disruptions, such as a tsunami and its aftermath, on the dynamics of the regions. For each region, we delivered a detailed country model that included 3-5 futures predictions in the 6-12 month range along with an analysis of conditions and casual links between predicted futures plus corresponding mitigated options. The project team worked closely with DARPA management to meet the requirements of DoD through the use of computational social science.

2.4 Facilities/Resources

As part of its dual and integrated focus on education and research, there are more than 3,000 ongoing projects on campus at MIT. These projects utilize shared centralized facilities, such as contemporary computational aids and library facilities, as well as specialized facilities of individual departments, research centers, and labs. Each project is affiliated with a nodal department, but can access resources in other parts of MIT. This project will draw particularly on MIT's extensive communications and network infrastructure.

The co-PIs are affiliated with various organizational units and research centers at MIT and will have access to their resources, especially the departments of Information Technologies, Political Science, Management Science, and the Technology, Management and Policy program, as well as key research centers, notably the Center for eBusiness (CeB), Center for Technology, Innovation, and Policy Development (CTIPD), the Center for International Studies (CIS), the Technology and Development Program (TDP), the Total Data Quality Management (TDQM) program, the Productivity from Information Technology (PROFIT) program, and the Laboratory for Energy and Environment (LFEE).

In this research effort we plan to work with many of our on-going collaborators, both via these Centers and individually, as reviewers, data sources, users (potential users of the models that we are developing), and collaborative researchers.

This project will primarily use existing computing equipment from the Context Interchange Systems (COIN) laboratory (within the Information Technology group of MIT's Sloan School of Management) and the Global System for Sustainable Development (GSSD) project (within MIT's Center for International Studies and Political Science department.) Both facilities are located in the same building, so coordination will be easy.

Equipment currently available within the COIN lab includes several Sun Unix servers, Windows NT servers, Linux servers, and Intel workstations running versions of Windows or Linux. In addition, we can draw on the Pentium workstations and Windows NT servers, and data sources of the GSSD. GSSD is the knowledge networking and management system for the Alliance for Global Sustainability (which includes MIT, University of Tokyo, Chalmers University-Sweden, and ETH - the Swiss Technical University System). GSSD mirror sites are maintained in France (École Nationale Supérieure des Mines de Saint Etienne), China (Ministry of Science and Technology) and Japan (University of Tokyo).

3.0 Schedule

The Statement of Work provides explanations of the tasks below. The schedule is primarily divided into quarterly deliverables. Phase 1 has 6 quarters, the other phases have 4 quarters each.

In addition to the tasks numbered below, Quarterly Progress reports will be prepared (except for those quarters where a Phase Completion Report is scheduled.)

Phase 1 (18 months) – Component Predictive Models Integrated into a Virtual World/Dynamic Gaming Collaborative Environment

Q1: 4.3.1.1
Q2: 4.3.1.2
Q3: 4.3.1.3, 4.3.1.4
Q4: 4.3.1.5, 4.3.1.6
Q5: 4.3.1.7, 4.3.1.8
Q6: 4.3.1.9

Phase 2 (12 months) – Prediction Using Specific Challenge Problem with Historical or Synthetic Data

Q1: 4.3.2.1
Q2: 4.3.2.2, 4.3.2.3, 4.3.2.4
Q3: 4.3.2.5
Q4: 4.3.2.6, 4.3.2.7

Phase 3 (12 months) – Prediction using Real World Data Instrumentation, Feedback and Fine tuning

Q1: 4.3.3.1
Q2: 4.3.3.2, 4.3.3.3, 4.3.3.4
Q3: 4.3.3.5
Q4: 4.3.3.6, 4.3.3.7, 4.3.3.8

Phase 4 (12 months) – Grand Challenge Problem: Influence Strategies for Alternative Futures

Q1: 4.3.4.1, 4.3.4.2
Q2: 4.3.4.3, 4.3.4.4
Q3: 4.3.4.5, 4.3.4.6
Q4: 4.3.4.7, 4.3.4.8

4.0 Program Organization

4.1 Organization Chart(s) with Key Personnel

MIT:

Prof. Stuart Madnick (MIT Sloan School, Information Technologies group & MIT School of Engineering, Engineering Systems Division) – Principal Investigator
Prof. Nazli Choucri (MIT Political Science department): Co-PI
Dr. Michael Siegel (MIT Sloan School, Information Technologies group): Co-PI

NSI (sub-contractor):

Dr. Robert Popp (Founder, Chairman, and CEO)
Gregory Ingram (Vice President for Operational Technology)

4.2 Management and Technical Team

4.2.1 Proposer Responsibilities

MIT takes the primary responsibility for all the tasks listed in the Statement of Work. NSI will support these activities, as explained immediately below.

4.2.2 SubContractor Responsibilities: National Security Innovations (NSI), Inc.

NSI is a business that specializes in providing innovative yet pragmatic scientific, technical, analytical, and programmatic services and technologies to complex 21st century national security problems by leveraging quantitative and computational modeling and analytical methods with principles from the social and physical sciences.

4.2.2.1 Objective

National Security Innovations (NSI), Inc will provide support to the System Dynamics effort by the MIT team by leveraging its experience with Quantitative Social Science modeling, program management, advanced knowledge discovery systems, and classified government analytical efforts. It will provide specific services pertaining to domain expertise, operational use case design, investigation and development of technology insertion partners, operational interface liaison within classified and unclassified analytical space, and testing and evaluation support.

4.2.2.2 Scope

Understanding the nature of relationships is rooted in knowing how an organization or a country functions and the principles that guide that functionality. Terrorist networks demand our attention today because of the apparent ease with which they inflict damage around the world.

We define the scope in terms of the dynamics of a state system, (including interactions among actors, actions, structures and processes in complex internal and external environments) seeking to manage its pressures given its capacities, while diminishing the loads and pressures exerted upon it. We propose to focus on, and model, three sets of dynamics processes: (a) the state and regime (b) the capacities of government; (c) sources and manifestations of terrorism – and the interactions among them in order to capture the propensities for overt terrorism.

4.2.2.3 Background and Capabilities

Understanding the growth of terrorist networks is an essential part of the Global War on Terrorism (GWOT). Applying System Dynamics (SD) modeling techniques can provide tremendous insights into the motivations, capabilities, and behaviors of terrorist groups that threaten regional stability and, by extension, national security.

There are a number of areas of prior work by the NSI team that relate to the proposed research. Both Dr Robert Popp and Greg Ingram have been involved in numerous classified government knowledge discovery (KD) and terrorist network modeling efforts. Some unclassified efforts include, but are not limited to, the DARPA Preconflict Analysis and Shaping (PCAS) effort and the Total Information Awareness (TIA) project

In addition, NSI is involved in other modeling and simulation (M&S) efforts funded by the Department of Defense concerning terrorist networks.

4.2.2.4 Tasks/Technical Requirements

4.2.2.4.1 Domain Expertise: Based on the extensive experience within NSI on terrorist networks, M&S, and KD systems over the past five years, NSI will provide domain expertise assistance to the MIT team. This expertise will include, but will not be limited to: lessons learned; access to other domain experts; and tactics, techniques, and procedures (TTPs).

4.2.2.4.2 Operational Use Case Design: NSI will provide input into the design of the Operational Use Case to include Target Audience Analysis, research and data gathering, data normalization support, workflow management support, and red teaming.

4.2.2.4.3 Testing and Evaluation Support: NSI will provide Testing and Evaluation (T&E) support to include test design, testing support, and access to operational testing environments,.

4.2.2.4.4 Operational Interface in Government Analytical Space: NSI has historical access to operational analytical spaces within the Department of Defense. NSI will broker information between the uncleared MIT team and cleared DoD personnel regarding sensitive and/or classified discussions concerning the MIT project.

4.2.2.4.5 Technology Insertion Partners: NSI will identify potential technology insertion partners for the evaluation, testing and transition of the SD technology.

4.3 <u>Resumes of Key Personnel</u>

All of the Key Personnel have considerable prior experience with the organization and management of large-scale projects that combine modeling and the assembling of diverse data with focused application requirements. They are all strongly motivated to produce results that are of significant impact.

Dr. Nazli Choucri is Professor of Political Science at the Massachusetts Institute of Technology, and Director of the Global System for Sustainable Development (GSSD), a distributed multi-lingual knowledge networking system to facilitate uses of knowledge for the management of dynamic strategic challenges. To date, GSSD is mirrored (i.e. synchronized and replicated) in China, Europe, and the Middle East in Chinese, Arabic, French and English. As a member of the MIT faculty for over thirty years, Professor Choucri's area of expertise is on modalities of conflict and violence in international relations. She served as General Editor of the International Political Science Review and is the founding Editor of the MIT Press Series on Global Environmental Accord. The author of nine books and over 120 articles Professor Choucri's core research is on conflict and collaboration in international relations. Her present research focus is on 'connectivity for sustainability', including e-learning, e-commerce, and e-development strategies. Dr. Choucri is Associate Director of MIT's Technology and Development Program, and Head of the Middle East Program. She has been involved in research, consulting, or advisory work for national and international agencies, and in many countries, including: Abu Dhabi, Algeria, Canada, Colombia, Egypt, France, Germany, Greece, Honduras, Japan, Kuwait, Mexico, North Yemen, Pakistan, Qatar, Sudan, Switzerland, Syria, Tunisia, Turkey

Dr. Stuart Madnick is the John Norris Maguire Professor of Information Technology, Sloan School of Management and Professor of Engineering Systems, School of Engineering at the Massachusetts Institute of Technology. He has been a faculty member at MIT since 1972. He has served as the head of MIT's Information Technologies Group for more than twenty years. He has also been a member of MIT's Laboratory for Computer Science, International Financial Services Research Center, and Center for Information Systems Research. Dr. Madnick is the author or co-author of over 250 books, articles, or reports including the classic textbook, *Operating Systems*, and the book, *The Dynamics of Software Development*, which received the Jay Wright Forrester Award for "Best Contribution to the field of System Dynamics in the preceding five years" awarded by the System Dynamics Society. His current research interests include connectivity among disparate distributed information systems, database technology, software project management, and the strategic use of information technology. He is presently co-Director of the PROductivity From Information Technology Initiative and co-Heads the Total Data Quality Management research program. He has been active in industry, as a key designer and developer of projects such as IBM's VM/370 operating system and Lockheed's DIALOG information retrieval system. He has served as a consultant to corporations, such as IBM, AT&T, and Citicorp. He has also been the founder or co-founder of high-tech firms, including Intercomp, Mitrol, and Cambridge Institute for Information Systems, iAggregate.com and currently operates a hotel in the 14th century Langley Castle in England. Dr. Madnick has degrees in Electrical Engineering (B.S. and M.S.), Management (M.S.), and Computer Science (Ph.D.) from MIT. He has been a Visiting Professor at Harvard University, Nanyang Technological University (Singapore), University of Newcastle (England), Technion (Israel), and Victoria University (New Zealand).

Dr. Michael Siegel is a Principal Research Scientist at the MIT Sloan School of Management. He is currently the Director of the Financial Services Special Interest Group at the MIT Center For eBusiness. Dr. Siegel's research interests include the use of information technology in financial risk management and global financial systems, eBusiness and financial services, global ebusiness opportunities, financial account aggregation, ROI analysis for online financial applications, heterogeneous database systems, managing data semantics, query optimization, intelligent database systems, and learning in database systems. He has taught a range of courses including Database Systems and Information Technology for Financial Services. He currently leads a research team looking at issues in strategy, technology and application for eBusiness in Financial Services.

Dr. Robert Popp is cofounder of National Security Innovations (NSI), Inc., presently serving as its Chairman and CEO. Prior to NSI, Dr. Popp served as Executive Vice President of Aptima, Inc. Prior to Aptima, Dr. Popp served for five years as a senior government executive within the Defense Department: one year at the Office of the Secretary of Defense as Assistant Deputy Undersecretary of Defense for Advanced Systems and Concepts, and four years at the Defense Advanced Research Projects Agency (DARPA). At DARPA, Dr. Popp served as Deputy of the Information Awareness Office (IAO) where he oversaw a portfolio of over 25 programs exceeding $170M focused on novel IT-based tools for counter-terrorism, foreign intelligence and national security. Dr. Popp was also Deputy PM to Dr. Poindexter on the Total Information Awareness (TIA) program, a program that integrated and experimented with analytical tools in text processing, collaboration, decision support, foreign languages, predictive modeling, pattern analysis, and privacy. Dr. Popp also served as Deputy of the Information Exploitation Office (IXO), where he established a novel research thrust in stability operations and quantitative/computational social science modeling for nation state instability and conflict analysis. Prior to government service, Dr. Popp held senior positions with ALPHATECH, Inc. (now BAE Systems) and BBN. He has served on the Defense Science Board (DSB), is a Senior Associate for the Center for Strategic and International Studies (CSIS), and is a founding Fellow of the Academy of Distinguished Engineers at the University of Connecticut. Dr. Popp also served in the military from 1982 – 1988 as a Staff Sergeant in the US Air Force as an Aircraft Maintenance Technician of F106 fighters and B52 bombers. Dr. Popp holds a Ph.D in Electrical Engineering from the University of Connecticut, and a BA/MA in Computer Science (summa cum laude, Phi Beta Kappa) from Boston University.

Gregory J. Ingram is the Vice President for Operational Technology for National Security Innovations (NSI), Inc. He has twenty-four years of experience in the Army in the fields of Special Forces, Infantry, Civil Affairs, and Psychological Operations (PSYOP). Fifteen of his twenty-four years have been on active duty and the remainder in the reserves. He has deployed in various capacities to Lebanon, Italy, Chile, Korea, Haiti, Afghanistan, and Iraq. For the last five years, Greg has been heavily involved in developing, integrating, and operationalizing leading-edge technologies in the areas of knowledge discovery, planning and analysis, human language technologies, and quantitative social science methodologies. Greg served as the lead PSYOP/IO Planner in the Special Operations Joint Interagency Collaboration Center (SOJICC) and as an Operational Manager for the development of the PSYOP Planning and Analysis System (POPAS) as part of the PSYOP Global Reach (PGR) Advanced Concept Technology Demonstration (ACTD) at the United States Special Operations Command (USSOCOM).

5.0 Appendix(es)

Very useful reference material can be found in this paper below, which is online at the address listed. Several of the other papers cited in the References are also available online.

Choucri, N., C. Electris, D. Goldsmith, S. Madnick, D. Mistree, J. B. Morrison, M. Siegel, and M. Sweitzer-Hamilton. (2006). "Understanding & Modeling State Stability: Exploiting System Dynamics," *Proceedings of the 2006 IEEE Aerospace Conference*, Big Sky, Montana, March 5-12, 2006. Available online: http://web.mit.edu/smadnick/www/wp/2006-02.pdf (Accessed February 3, 2007.)

An even more detailed version of that paper can be found in this report, "Understanding & Modeling State Stability: Exploiting System Dynamics (PCAS Final Report with Appendices)," which can be found online at: http://web.mit.edu/smadnick/www/wp/2005-13.pdf

PART II --- Offeror Statement of Work

1.0 Objective:

This section is intended to give a brief overview of the specialty area and should describe why it is being pursued, and what you are trying to accomplish.

The objective is use System Dynamics (SD) to develop predictive models of situations that threaten the US. By focusing on the individual causal factors, their interactions, and their evolution over time, we will use this methodology to provide an integrative approach applicable to different contexts in diverse areas. We propose to demonstrate the capability of using SD modeling methodology to meet PAINT's four goals by answering the following Grand Challenge question:

> *How should the Government analyze terrorist networks in the context of the political, religious, social and economic networks that intersect with, influence, and are influenced by, the terrorist network; predict the formation, evolution, vulnerabilities, and dissolution of the network; and identify strategies to shape or influence the network through selective action?*

2.0 Scope:

Understanding the nature of these relationships is rooted in knowing how an organization or a country functions and the principles that guide that functionality. Terrorist networks demand our attention today because of the apparent ease with which they inflict damage around the world. The increased impact has partially arisen by the availability of the technology that allows a hostile group global access – this enables the terrorist organization to accelerate its learning cycle and magnify its "messaging" ability. Modeling and understanding the problems created by these new capabilities is a central focus of our proposed efforts.

We define the scope in terms of the dynamics of a state system, (including interactions among actors, actions, structures and processes in complex internal and external environments) seeking to manage its pressures given its capacities, while diminishing the loads and pressures exerted upon it. We propose to focus on, and model, three sets of dynamics processes-- (a) the state and regime (b) the capacities of government; (c) sources and manifestations of terrorism – and the interactions among them in order to capture the propensities for overt terrorism.

3.0 Background:

Understanding the growth of terrorist networks is an essential part of the Global War on Terrorism (GWOT). Applying System Dynamics (SD) modeling techniques can provide tremendous insights into the motivations, capabilities, and behaviors of terrorist groups that threaten regional stability and, by extension, national security. These inputs can directly affect the efficiency by which the U.S. and its allies deal with terrorist networks. We propose to develop a SD model of the state system, the major actors, and their interactions which will provide insights for understanding and mitigating terrorist growth and activity.

There are a number of areas of prior work by this team that relate to the proposed research. These are the use of System Dynamics as a modeling tool, the recent development of State Stability Models for DARPA's Pre-Conflict Analysis and Shaping (PCAS) effort including the use of these results in PACOM's Theater Security Cooperation (TSC) Planning, the earlier work for CIA and DIA on Security in Central Asia, and the set of modeling and simulation studies on conflict and violence in international relations focusing on competition among major powers.

In addition, we have begun to model the fundamental dilemmas inherent in a government seeking to meet the demands of its people while, at the same time, faced with pressures that undermine its own stability, impeding its capacities to meet demands, and providing opponents with a logic for dissidence as a breeding ground for terrorism.

4.0 Tasks/Technical Requirements

4.1 Goals/Intended Accomplishments

We propose to develop a general System Dynamics (SD) model that will be predictive of situations involving terrorist networks that threaten the US, by focusing on the causal factors, their interactions, and their evolution over time. We intend to use this methodology to provide a generalizable integrative approach applicable to different contexts in diverse areas.

This scalable parameterizable model will include interactions among populations, government actions, and terrorist networks that will give analysts the ability to anticipate reactions to events, estimate ranges of outcomes to various courses of action, and assist in the planning of operations.

In addition to the interactions among populations, governments, and terrorist networks, the model shall also include:

- The interactions among nations, their populations and the terrorist networks resident in their region. Since these interactions will differ by nation, the simulated model behavior in each country/region sub-model will vary accordingly.
- The interactions among both US military and non-military organizations and the above mentioned parties. Distinct feedback loops representing the effects of US actions as well as host/partner country actions would allow for the analysis of varying combinations of actions in each area of interest.

The model will be an explicit mathematical representation of a causal theory of the dynamics of the problem of interest using the tools of system dynamics by represent the casual components of the theory in stocks, flow, and feedback structure and translation of the causal theory both into standard SD icons and into an explicit mathematical representation in System Dynamics modeling simulation software. We propose to develop, execute, and document a methodology to provide estimates of the needed parameter values to demonstrate and validate the model behavior. In addition to the Government furnished data to be provided in this project, we plan to work with our colleagues to identify and gather subject matter expertise in the various domains relevant to terrorist networks so as to refine the parameter values.

Our ultimate goal is to demonstrate the capability of using System Dynamics modeling methodology (SDM) to meet PAINT’s four goals by answering the following Grand Challenge question:

How should the Government analyze terrorist networks in the context of the political, religious, social and economic networks that intersect with, influence, and are influenced by, the terrorist network; predict the formation, evolution, vulnerabilities, and dissolution of the network; and identify strategies to shape or influence the network through selective action?

4.2 Technical Approach

Our technical approach consist of four major features:

(a) *modular framework* for modeling the dynamics of terrorism,

(a) strategy for *integrating* the modules or components;

(c) work plan consisting of *four Phases,* each generating specific results and providing for basis for the next steps, and

(d) *linkage strategy* that connects the system dynamics modeling of terrorism and our analysis of the Grand Challenge to the other PAINT areas of dynamics gaming and strategies, key indicators and measurements, and architecture and integration.

4.3 Four Phases – Tasks and Products

The tasks in each Phase are defined by increasing complexity along multiple dimensions: (1) increasing sophistication of the System Dynamics model, (2) increasing complexity of challenge problem, (3) data that tends increasingly towards near real-time, real-world data, (4) increasing speed of development and adaptability of dynamic simulation and gaming models, and (5) increasing complex user-model interactions.

The High Level (HLM) System Dynamics model to be developed is envisioned of consisting of three major sub-systems (each with sub-modules or sub-systems as needed) to represent the dynamics of:

(a) *regime resilience*
(b) *government capacity,* and
(c) *terrorist network activities and growth.*

Although progress and refinement of the entire model will occur during each Phase, we propose to focus intensely on a specific sub-system during each phase, as further explained below.

4.3.1 Phase 1 (18 months) – Component Predictive Models Integrated into a Virtual World/Dynamic Gaming Collaborative Environment

4.3.1.1 The key task is to design, develop, and complete the High Level Model (HLM) of a System Dynamics Model of the Dynamics of Terrorist Networks. The HLM shall consist of three major sub-systems (each with sub-modules as needed) to represent the dynamics of:

(a) *regime resilience*
(b) *government capacity,* and
(c) *terrorist network activities and growth.*

4.3.1.2 The set of basic data for the HLM shall be compiled to provide an empirical view of the overall model and the basis for more defining detailed data need for the next phases

4.3.1.3 The basic set of specific SDM country and case models shall be defined and basic information compiled and formatted for future reference (including inputs for domain experts).

4.3.1.4 Initial empirical analysis of the country-case data sets shall be undertaken in order to determine similarities and differences among the factors that influence the basic parameters of the model, and to enable us to distinguish between generic features versus idiosyncratic elements.

4.3.1.5 Compilation of expert-based information on (i) known as well as potential similarities and differences among the country-cases selected and (ii) extent of reliability of publically accessible data bases.

4.3.1.6 Develop the criteria and the HLM specifications in order to account for and represent terrorist influences and behaviors across counties and cases modeled.

4.3.1.7 Obtain expert-based information on (i) known as well as potential similarities and differences of terrorist influences across countries cross-country and among the country-cases selected and (ii) extent of reliability of publicly accessible data bases about indicators of terrorism influence across cases.

4.3.1.8 Identify and coordinate the high level connections of the HLM to the PAINT areas of dynamic gaming and strategies, key indicators and architecture and integration.

4.3.1.9   Produce Phase 1 report summarizing accomplishments of this phase. This report shall document all technical work accomplished and information gained during this phase. This shall include all pertinent observations, nature of problems, positive as well as negative results, and design criteria established, where applicable; also, procedures followed, processes developed, "Lesson Learned", etc. The details of all technical work shall be documented to permit full understanding of the techniques and procedures used.

4.3.1.10 Shall conduct presentations/meetings at times and places specified in the contract schedule.

4.3.2 **Phase 2** (12 months) **– Prediction Using Specific Challenge Problem with Historical or Synthetic Data**

4.3.2.1 All subsystems of the HLM shall be enhanced based on results from Phase 1 as well as new sources of information and feedback.

4.3.2.2 In this phase there shall be specific focus on the *regime resilience* module or subsystem of the HLM and the development of a more detailed set of equations representing the dynamics of this module.   This includes key elements of the economy, the society and its various groups, and the polity. These are the very elements that terrorists seek to attack in order to undermine the viability of the country as a whole.

4.3.2.3 The set of basic data for the regime resilience module shall be further developed, extending the compilations made in Phase 1. This extension is designed to provide greater empirical foundations for the Integrated Model in Phase 4.

4.3.2.4 The data shall be used to parameterize the regime resilience module and provide the basis for modeling and simulation under alternative assumptions.

4.3.2.5 Prediction of regime resilience module shall be undertaken with the use of historical data as well as synthetic observations

4.3.2.6 Expansion of the high level connections identified Phase 1 - relating the HLM to dynamic gaming and strategies, key indicators and architecture and integration.

4.3.2.7 Produce Phase 2 report summarizing accomplishments of this phase. This report shall document all technical work accomplished and information gained during this phase. This shall include all pertinent observations, nature of problems, positive as well as negative results, and design criteria established, where applicable; also, procedures followed, processes developed, "Lesson Learned", etc. The details of all technical work shall be documented to permit full understanding of the techniques and procedures used.

4.3.2.8 Shall conduct presentations/meetings at times and places specified in the contract schedule. Shall broaden the target groups and the location of meetings in order to obtain as wide a range of reactions and assessments feasible.

4.3.3 Phase 3 (12 months) – Prediction using Real World Data Instrumentation, Feedback and Fine tuning

4.3.3.1 All subsystems of the HLM shall be enhanced based on results from Phase 2 as well as new sources of information and feedback.

4.3.3.2 In this phase there shall be specific focus on the *terrorist network activities and growth* module or subsystem of the HLM and the development of a more detailed set of equations representing the dynamics of this module.

4.3.3.3 The set of basic data for all the modules shall be further developed, extending the compilations made in Phase 2. This extension is designed to provide greater empirical foundations for the Integrated Model in Phase 4.

4.3.3.4 The data shall be used to parameterize this module and provide the basis for modeling and simulation under alternative assumptions.

4.3.3.5 Predictions generated from the *terrorist network activities and growth* module shall be undertaken with the use of historical data as well as synthetic observations

4.3.3.6 The full integrated system dynamics model shall be extensively tested, using real world data instrumentation, feedback and fine tuning.

4.3.3.7 Expansion of the high level connections undertaken Phase 2 - relating the HLM to dynamic gaming and strategies, key indicators and architecture and integration.

4.3.3.8 Produce Phase 3 report summarizing accomplishments of this phase. This report shall document all technical work accomplished and information gained during this phase. This shall include all pertinent observations, nature of problems, positive as well as negative results, and design criteria established, where applicable; also, procedures followed, processes developed, "Lesson Learned", etc. The details of all technical work shall be documented to permit full understanding of the techniques and procedures used.

4.3.3.9 Shall conduct presentations/meetings at times and places specified in the contract schedule.

4.3.4 Phase 4 (12 months) – Grand Challenge Problem: Influence Strategies for Alternative Futures

4.3.4.1 All subsystems of the HLM shall be enhanced based on results from Phase 3 as well as new sources of information and feedback.

4.3.4.2 In this phase there shall be specific focus on the *government capacity* module or subsystem of the HLM, the development of a more detailed set of equations representing the dynamics of this module.

4.3.4.3 The set of basic data for all the modules shall be further developed, extending the compilations made in Phase 3.

4.3.4.4 We shall complete the full integration and testing of all modules in the system dynamics model, as well as undertake simulations, robustness analysis, and predictions.

4.3.4.5 We shall intensely address the Grand Challenge problem by focusing on the influence strategies for alternative futures in determining how should the Government analyze terrorist networks in the context of the political, religious, social and economic networks that intersect with, influence, and are influenced by, the terrorist network; predict the formation, evolution, vulnerabilities, and dissolution of the network; and identify strategies to shape or influence the network through selective action.

4.3.4.6 We shall identify the key policy levers and intervention points in the SDM model, and examine the effects of alternative ways of controlling the impacts.

4.3.4.7 We shall complete connections of the SD modeling effort and its results with the other PAINT areas of dynamic gaming and strategies, key indicators and architecture and integration.

4.3.4.8 Produce Phase 4 report summarizing accomplishments of this phase. This report shall document all technical work accomplished and information gained during this phase. This shall include all pertinent observations, nature of problems, positive as well as negative results, and design criteria established, where applicable; also, procedures followed, processes developed, "Lesson Learned", etc. The details of all technical work shall be documented to permit full understanding of the techniques and procedures used.

4.3.4.9 Shall conduct presentations/meetings at times and places specified in the contract schedule. In his last Phase we shall broaden the target groups and the location of meetings even more in order to expand further the reactions and assessments obtained.

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