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Title: Planning For Manned And Unmanned Entities in Net-Centric Environment: Missions and Means Framework, Multi-Agent Simulation

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Name Of Author(s): Kofi Nyamekye, Ph.D.
* Maarten Sierhuis, Ph.D.
* Ron van Hoof, Computer Scientist

Point of Contact: Kofi Nyamekye, Ph.D.

Name of Organization: INTEGRATED ACTIVITY-BASED SIMULATION RESEARCH, INC.

Address: P.O. BOX 421, Rolla, MO 65402

Telephone: 573-341-2141

E-mail address: kofinsoyameye@earthlink.net

* NASA Ames Research Center

ABSTRACT

Today, achieving collaborative tactical planning on the battlefield presents a significant challenge in the new DoD Net-Centric systems-of-systems (SoS) and the futuristic integrated and adaptive C4ISR systems-of-systems. The primary reason is that in a Net-Centric environment both manned and unmanned heterogeneous platforms and robotic systems must work side-by-side with the warfighters, but the current tactical planning architectures are not well suited for such mixed entities. Also, the unmanned entities may not have the cognitive architecture to stop executing the battlefield plan even if the conditions on the battlefield changes. Such entities must also be networked together to execute the tasks in the battlefield plan that may involve many stakeholders with different agendas, for example in complex civil-military endeavors. The paper first provides a brief overview of the industrial age military planning followed by the new collaborative tactical planning approach for Net-Centric Warfare (NCW). Using the Issue-Based Information Systems (IBIS) concepts with Compendium as an example of a generic IBIS for solving wicked problems such as planning, NASA Brahms multi-agent oriented modeling and simulation language as a generic language, and Missions and Means Framework Model, the paper discusses the design of a generic high-level architecture for distributed collaborative tactical planning. The paper then discusses Design Navigation Method; a design scientific method that uses minimum information content theory to evaluate the tactical test plans.

INTRODUCTION

Traditional tactical planning to support the United States Department of Defense (DoD) battlefield missions involves humans that collaborate through radio communications to manually decide the tasks to be performed to achieve a mission. Current manual planning is time consuming and more importantly does not support the Net-Centric environment. Compounding the technical challenge in tactical mission planning is the new DoD Net-Centric systems-of-systems (SoS) or the Global Information Grid (GIG), which consists of several Net-Centric components such as the futuristic integrated and adaptive Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) SoS, such as the Army Future Combat Systems (FCS). These Net-Centric SoS components involve both manned and unmanned heterogeneous platforms and robotic systems that must work side-by-side with the warfighters. Today the warfighters may also work side-by-side with friendly adversaries on the battlefield. Such adversaries may have different social and cultural agendas such as in complex civil-military endeavors [Alberts et al. 2007]. By complex civil-military endeavors we mean battlefield operations that may involve tribal leaders and local tribesmen that would collaborate with the U.S. Army or other U.S. military organizations to provide military intelligence to support the collaborative tactical planning for counterinsurgency operations. The Tall Afar and Al Anbar Province counterinsurgency models in Iraq are examples of such complex civil-military endeavors [Alberts et al. 2007]. Because Net-Centric SoS is very complex, it is extremely difficult to capture the interactions among the various entities with manual planning. Moreover, the use of manual planning in such environments may result in coupling among the mission requirements. For example, suppose the mission requirements on the battlefield, especially in an urban environment are: “destroy the enemy” and “achieve a certain range of collateral damage”. Then what we mean by coupling among the mission requirements is that “destroy the enemy” requirement should not affect the “achieve a certain range of collateral damage" requirement. Thus, we need a new approach to DoD tactical planning to achieve a DoD battlefield mission, especially for complex civil-military endeavors, which may involves different stakeholders with different cultural and social backgrounds, advanced manned and unmanned systems, and other stake holders such as NGOs (non-governmental organizations), in Net-Centric environments. Current tactical planning models are inadequate to support such heterogeneous mixed entities.

Using the author's previous work on designing C4ISR systems-of-systems [Nyamekye June 2007; Nyamekye June 2008], the Missions and Means Framework, Issue-Based Information Systems and multi-agent simulation concepts, this paper establishes the generic technical and scientific architecture for designing the high level distributed collaborative tactical planning system for the battlefield, in Net-Centric environment.

The organization of this paper is as follows. First, we will provide the literature review for planning, which includes a brief overview of industrial age military planning, and Net-Centric approach for planning as recently espoused by Alberts et al. [Alberts et al. 2007]. Second, we will discuss that collaborative tactical planning design is an example of a "wicked problem", a concept originally pioneered by Rittel [Rittel et al. 1973]. We will note that Rittel's thinking about planning is in agreement with coupling among the functional requirements in Axiomatic Design, pioneered by Nam P. Suh, from Massachusetts Institute of Technology [Suh 1990; Suh 2001]. We will also discuss Issue-Based Information Systems [Kunz and Rittel May 1979], a theoretical concept envisioned by Rittel for a design approach, which involves collaboration and shared understanding among stakeholders, typical in collaborative tactical planning, with different agendas such as in complex civil-military endeavors, for solving wicked problems. We will borrow from Corollary 4 of Axiomatic Design and treat Issue-Based Information Systems as an extension of Corollary 4 for collaborative tactical planning. We will discuss open source research and development systems, such as Compendium [Compendium], for addressing wicked problems through collaboration and shared understanding. Third, we will discuss multi-agent modeling and simulation approaches with emphasis on natural intelligence capabilities (cognitive capabilities) and social behaviors for handling communication and collaboration among many different stakeholders including humans, manned and unmanned entities in a Net-Centric environment. We will note that NASA's Brahms [Sierhuis 2001] and multi-agent modeling and simulation language that has been previous employed to design collaborative planning among different entities in NASA's Space Missions, addresses cognitive and social scientific aspects of group behaviors typical in complex endeavors. Thus, Brahms would be appropriate for Net-Centric planning. Fourth, we will discuss the Missions and Means Framework (MMF) Model [Dietz and Sheehan May 9 2006; Watkins et al.], followed by the generic high-level architecture design for collaborative tactical planning (borrowing from the principles of ***Power to the Edge***), and minimum information content (AXIOM 2 of Axiomatic Design), for performance evaluation. Conclusions will then follow. In this paper we will treat the design of the plan models and the test of the plan models--plan's execution--to occur concurrently [Alberts et al. 2007].

LITERATURE REVIEW

Alberts et al. have provided much detailed discussion about the traditional approaches to military planning and new approaches to planning for Net-Centric Operations (NCO). Rather than delving into details of their work, we will briefly summarize it. According to these investigators, the traditional military planning begins with establishing the goal or objective (Command Intent), within the context of the specific situation. The specific situation may be a major threat from insurgents, or a natural disaster such as Katrina requiring major humanitarian help. The military planning processes involve the interpretation of the Command Intent, which is conveyed down the hierarchical chain of command. The final output of the planning process is a set of plans, which must be executed. Planning and execution are treated as separate processes indeed.

Furthermore, Alberts et al. point out that centralized planning is the hallmark of the traditional military approaches to Command and Control (C2). The plan or set of plans that the traditional planning process produces are much detailed, inflexible and require considerable amount of time to develop. Thus, dynamic planning in respond to uncertainties on the battlefield is not an option in traditional military planning process. The thinking behind such inflexible detailed plan(s) is that the adversary operated in a static environment with fixed targets. With an adversary hunkered down in a static environment, the industrial age military commanders could use such plans as the mechanisms to impose their will on such an adversary. In fact, this was the Cold War model, which is the same as traditional hierarchical Command and Control planning model.

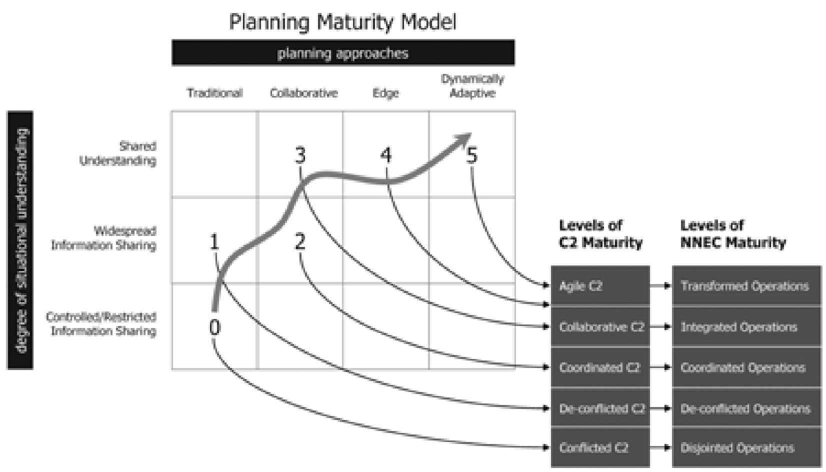

Figure 1. Net-Centric Capability and Command and Control Planning Maturity Models (NCCC2PMM) [Alberts et al. 2007].

In recognition of the deficiencies of the centralized planning for Net-Centric Operations, Alberts et al. [Alberts et al. 2007] have established a new conceptual planning model for Net-Centric enterprise ecosystem. Using the Net-Centric Warfare (NCW) Maturity Model [Alberts et al. 2003], as the theoretical foundation, the NATO Network Enabled Capability, and linking NATO Network Enabled Capability to the new Command and Control, they have designed new integrated planning models shown in Figure 1. In this paper we call such integrated models as Net-Centric Capability and Command and Control Planning Maturity Models (NCCC2PMM).

Please note that Conflicted C2 is associated with controlled or heavily restricted information sharing (information is not shared across organizational boundaries) and traditional planning (meaning independent planning by each element of the force). This represents Position 0 in the Planning Maturity Model [Alberts et al. 2007].

As information sharing becomes more widespread, a more mature type of planning becomes possible (Position 1) because the planning within each element is now performed within the context of considerable knowledge about the boundaries between functions and organizational areas of responsibility. Hence, while still independent, the resulting plans should not create negative cross impacts. This corresponds to De-Conflicted C2 [Alberts et al. 2007].

As collaborative planning becomes possible, Position 2 becomes available because selected activities become synchronized (purposefully organized in time and space) in order to achieve synergies in some specific efforts. This is intended to generate synergistic effects. Position 2 is the first level of planning maturity at which such synergies are consciously sought during the planning process and this level corresponds to Coordinated C2 [Alberts et al. 2007].

Moving to Position 3 becomes possible as the level of information sharing and collaboration allow the different elements of the endeavor to achieve shared understandings, which means that they see the problem in the same way and can agree on the classes of activities in which they expect to have positive effects. If this is accompanied by a change to collaborative planning processes, then all of the requirements for Position 3 are fulfilled. However, to achieve this level the interactions (information exchanges, collaborative planning processes) will need to be, for all intents and purposes, continuous. That is, the frequency is matched to the dynamics of the situation. This level of planning maturity maps to Collaborative C2 [Alberts et al. 2007].

Achieving Position 4 implies more than collaborative planning processes and shared understanding. Every element of the force must be willing to depend on the other elements for crucial support and resources, typical in collaborative tactical planning. Hence, the level of planning moves beyond collaboration when operating at Position 4. Each force element accepts an overall negotiated set of intents and approaches to mission success and subordinates its own planning efforts to that construct. Hence, each force element sees itself as both the "main effort" and also a crucial "supporting effort" upon which others must depend. Positions not only require the ability to self-synchronize, but also the ability to adapt dynamically. This requires the capability to identify and execute at the requisite level of maturity [Alberts et al. 2007]. Thus, in this paper we refer to Position 4 as the collaborative tactical planning for the warfighters on the battlefield.

Position 5 achieves distributed dynamic collaborative tactical planning, which the authors' of this paper call "distributed adaptive collaborative planning." In this paper our focus will be in designing the architecture for achieving Position 4 – "distributed collaborative tactical planning." The next sections discuss the approach for designing the architecture for distributed collaborative tactical planning on the battlefield.

RITTEL's GENERAL THEORY OF PLANNING: ISSUE-BASED INFORMATION SYSTEMS

Through extensive research in social planning, at University of California Berkeley, Rittel recognized that planning is a "wicked problem", a phrase that he used in social planning to describe a problem that is difficult or impossible to solve because of incomplete, contradictory, and changing requirements that are often difficult to recognize. He noted that social planning involves stakeholders who have different worldviews and understanding of the problem at hand. Please note that social planning shares the same similarities as collaborative tactical planning among the warfighters and other stakeholders on the battlefield. More importantly, he criticized the inadequacy of existing Newtonian-based scientific and professional processes such as Operation Research methods for addressing such problems, because traditional and formulaic processes cannot solve wicked problems [Rittel et al. 1973; Rith and Dubberly 2006]. He suggested that the ideal planning model is a cybernetic—goal-oriented and involving feedback—process [Rith and Dubberly 2006].

In recognition of this need Rittel [Kunz and Rittel May 1979] established a generic concept known as Issue-Based Information Systems (IBIS) to support coordination and planning of political decision processes. The IBIS guides the identification, structuring, and settling of issues raised by problem-solving groups, and provides information pertinent to the discourse. Elements of the system are topics, issues, and questions of fact, positions, arguments, and model problems. The logic of issues, the subsystems of IBIS, and their rules of operation are outlined during planning of the political decision processes, among participants (with different cognitive architectures and knowledge, social and political agendas). By cognitive architecture, we mean structures that determine mental processing -- the shape of mental mechanisms responsible for cognitive achievements. What we are saying here is that each participant processes information differently and hence the participants in collaborative tactical planning must be aware of such an issue. To illustrate his IBIS concept, he defined a planning task by name “trigger task” which was an example of social planning of a political decision process (“Urban Renewal in Baltimore,” “The War,” “Tax Reform”) [Kunz and Rittel May 1979]. He viewed such a planning task as an example of an initially unstructured problem area or topic for which the classical scientific methods could not address [Kunz and Rittel May 1979]. About this topic and its subtopics, a discourse develops [Kunz and Rittel May 1979]. Issues are brought up among the participants. The issues are then disputed because different positions are assumed among the participants [Kunz and Rittel May 1979], such as between warfighters and the friendly adversaries who may view the battlefield mission differently. Arguments are constructed in defense of or against the different positions until the issue is settled by convincing the opponents or decided by a formal decision procedure [Kunz and Rittel May 1979]. Frequently questions of fact are directed to experts (agents) or fed into a documentation system of the IBIS [Kunz and Rittel May 1979]. Answers obtained can be questioned and turned into issues. Through this counter-play of questioning and arguing, the participants of the planning form and exert their judgments iteratively, developing more structured pictures of the problem and its solutions [Kunz and Rittel May 1979]. According to Rittel, it is not possible to separate “understanding the problem” as a phase from “information” or “solution” since every formulation of the problem is also a statement about a potential solution [Kunz and Rittel May 1979]. When we compare the collaborative tactical planning approach for Net-Centric Operations with Rittel’s example, the different stakeholders in Net-Centric environment, for example in counterinsurgency operations in which the U.S. forces may collaborate with the local tribesmen (with different social and cultural beliefs) for urban planning, the entities in Net-Centric environments share the same cognitive and social behaviors as noted in this illustration. Thus, it is fitting to say that IBIS can aid in collaborative tactical planning for Net-Centric Operations.

Borrowing from Rittel's work, Conklin [Conklin 2005] established the Dialogue Mapping concept, which is structural augmentation of group communication. A map serves as a vehicle for assembling different ideas, arguments, questions, and so on during communication among different stakeholders. As the conversation unfolds and the map grows, each person can see a summary of the meeting discussion so far. Consequently, the map serves as a "group memory," virtually eliminating the need for participants to repeat themselves to get their points made.

Recent advances in IBIS have led to the design of Compendium as an open source research and development tool for addressing wicked problems. A brief overview of Compendium is essential. Compendium is about sharing ideas, creating artifacts, making things together, and breaking down the boundaries between dialogue, artifact, knowledge, and data. It helps provide a faster, better way for groups and project teams to work. Of particular importance is the concept of hypertext, which is the art, design, engineering, and science of relationships. According to Noll et al. [Noll et al. 1999], *"(h)ypertext is an information management concept that organizes data into content objects called nodes, containing text, graphics, binary data, or possibly audio and video, that are connected by links which establish* ***relationships*** *between nodes or sub-parts of nodes. The resulting directed graph … forms a semantic network-like structure that can capture rich data organization concepts while at the same time providing intuitive user interaction via navigational browsing."* Compendium offers a superior research and development tool for addressing semantic interoperability, a typical research issue in designing distributed collaborative planning for Net-Centric environments. In fact, NASA Ames Research Center was among the early investigators to use Compendium map, to design collaborative planning systems for NASA Space Missions [http://compendium.open.ac.uk/institute/images/nasa4.jpg].

IBIS and Axiomatic Design

An interesting point to note is the similarities between the Axiomatic Design and IBIS. Suppose two ideas (functional requirements) in planning are: 1) "Defeat the insurgents" 2) "Avoid collateral damage". If executing 1 causes 2 to occur, then idea 1 influences ideas 2. In Axiomatic Design, we say that coupling exits between both ideas. Rittel calls such a scenario complex interdependency between idea 1 and 2, and it is such a type of a scenario that makes it extremely challenging to solve wicked problems. In IBIS the participants can easily discuss such interdependencies through maps and come up with remedial action to eliminate coupling. For example rather than using Hellfire missile, which may cause collateral damage, the participants can agree to use the friendly adversary with the same social and cultural backgrounds as insurgents to root out the insurgents. For convenience we have summarized Suh's work, AXIOM 1 and AXIOM 2, and the main corollaries and theorem for planning design, systems-of-systems (SoS) design, and so on [Suh 1990; Suh 2001]. For more details on both axioms and corollaries, please see Nyamekye's previous work on C4ISR SoS [Nyamekye June 2007; Nyamekye June 2008]. We will draw on this concept for evaluating the plans using the measures-of-merit (MOM) [Alberts et al. 2007].

AXIOM 1: In a good design, the independence of functional requirements (FRs) is maintained.
AXIOM 2: The design that has the minimum information content is the optimal design.

Corollary 1: Decoupling of Coupled Design: Decouple or separate parts or aspects of a solution if FRs are coupled or become interdependent in the proposed designs.
Corollary 2: Minimization of FRs: Minimize the number of functional requirements and constraints. Strive for maximum simplicity in overall design or the utmost simplicity in physical and functional characteristics.
Corollary 3: Integration of Physical Parts: Integrate design features into a single physical process, device, or system when FRs can be independently satisfied in the proposed solution.
Corollary 4: Use of Standardization: Use standardized or interchangeable parts, architecture, process, device, scientific concept, or system if the use of these parts, architecture, process, device, scientific concept, or system is consistent with the FRs and constraints.

THEOREM M2 (Large System with Several Subunits) When a large (e.g., organization) consists of several subunits, each unit must satisfy independent subsets of FRs so as to eliminate the possibility of creating a resource-intensive system or a coupled design for the entire system.

AXIOM 1 basically reinforces Rittel's work on complex interdependencies among ideas. AXIOM 2 also emphasizes uncertainties (entropy) that Rittel's noted could crop up in collaborative tactical planning. Because different stakeholders have different agendas, even after initially agreeing to a plan some stakeholders may change their mind by raising new issues, which may require new research (more information) to draw up a new plan altogether. The IBIS provides the theoretical base that encourages each participant to voice their concerns upfront and map them to resolve any new issues that may crop in the final plan, thereby minimizing any uncertainties (or reducing information content – AXIOM 2) in the final plan. Because Rittel's work has recently been recognized as the standard scientific concept for solving wicked problems [Rith and Dubberly 2006], we will consider IBIS as an extension of Corollary 4 to address wicked problems.

MULTI-AGENT SYSTEMS

An intriguing part of Rittel's work was that when the participants in collaborative planning face frequently questions of fact, such as a specific technical or scientific research question in political planning decisions, the Rittel's IBIS says that we must refer them to experts, for example leading experts in the field, for answers. In distributed collaborative tactical planning systems, seeking answers to questions by the planners and plan executors from outside experts on the battlefield, may not be feasible due to the rapidly changing dynamic nature on the battlefield. Thus, we need intelligent agents with capabilities for natural intelligence reasoning to provide answers to frequently questions of fact in Net-Centric environments. Multi-agent entities, with natural intelligence reasoning, provide such an answer. While much literature exists on multi-agent systems, we are much interested in entities with such capabilities that can humanize their activities, but not agents whose reasoning is based on the classical artificial intelligence approach. As Sierhuis [Sierhuis 2001] puts it, people are inherently social actors and so, we must be concerned with the social dimension of action and knowledge. Particularly in counterinsurgency operations the participants in collaborative tactical planning may contemplate that using an unmanned entity such as a Hellfire missile to attack insurgents in urban environments, may create significant backlash from the press and the civilian population if such combat operations result in collateral damage. Thus, during planning, the warfighters and the friendly adversaries may decide that if such an unmanned entity (through natural reasoning from the situation awareness) detect that it does not have clear information about whether the "bad guys" have intermingled themselves with the friendly population, then the unmanned entity must not execute the plan. Rather it must convey such intelligent information to other warfighters and the friendly adversaries, for other possible alternatives to attack the insurgents. That is, we want any unmanned entity to have a natural intelligence to reason from the situation awareness of the threat environment just like a human being that even if it receives orders to destroy the enemy in the threat environment surrounded by school children, it should convey to the entities on the ground the potential for causing collateral damage and thus other combat operations should be quickly explored. In fact the unmanned entity could even suggest to other entities on the ground the consequences such as the civilian backlash against such an attack. Intriguingly, Rittel noted a similar problem with entities, such as intelligent robots, based on "artificial intelligence" approach [Rith and Dubberly 2006]. He criticized attempts by artificial intelligence researchers to mimic the brain, and instead proposed research to find tools or "mental crutches" that enhance "natural intelligence" [Rith and Dubberly 2006]. He provided guidelines for more "natural intelligence-reinforcement" systems that cast doubt, point out ignorance, and thus are more useful because they open up new possibilities for shared understanding and collaboration among entities with different cognitive architectures and social values in collaborative planning [Rith and Dubberly 2006].

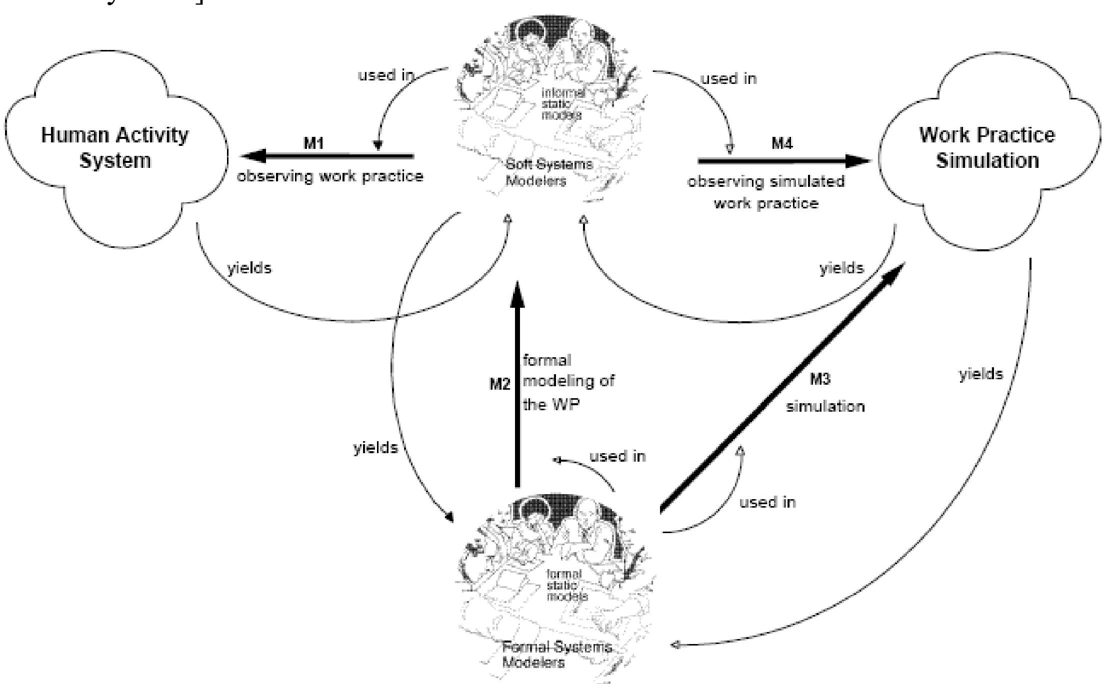

Figure 2. Brahms Architecture [Sierhuis 2001].

Gasser also noted that the classical artificial intelligence (AI) research is largely *a-social*, meaning that the unit of analysis is a computational process with a single locus of control and knowledge [Gasser 1991]. Thus, AI has been inadequate in dealing with social human behavior. Gasser investigated how the classical distributed artificial intelligence (DAI) deals with the *social* conception of knowledge, action, and interaction. He made an argument that distributed artificial intelligence (DAI) is fundamental in the research on how agents coordinate their actions, use knowledge about beliefs, and reason about the beliefs and actions of other agents. He further asserted that the traditional techniques and methods of AI do not include any fundamental social elements. Rather, the focus is on the individual as the object of knowledge, truth and knowing.

Gasser gave an intriguing example of such a limitation in the AI research. Sierhuis provided in-depth review of the two most popular DAI systems, in terms of their ability to represent people's collaboration, "off-task" behaviors, multi-tasking, interrupted and resumed activities, informal interaction, knowledge and geography [Sierhuis 2001]. He noted that none of the DAI systems has the capabilities for collaboration among entities. This issue is very important in distributed collaborative tactical planning among entities with different social and cultural values. In recognition of this need Sierhuis designed Brahms, an agent oriented language, for his doctoral thesis work. Figure 2 shows the architecture of Brahms. For simplicity, we have omitted the details of Figure 2. Originally designed for modeling and simulating work practice, Brahms multi-agent modeling and simulation language has been extensively used to create distributed collaborative tactical planning of Human-Robotic Exploration Activity in Space Mission operations, including the collaborative tactical planning for the recent successful Phoenix Mars Lander.

Today, Brahms has been the generic modeling and simulation research language for conducting research for all NASA's Space Mission programs. Unlike other systems, it has the capability for designing multi-agent modeling and simulation systems with cognitive architectures and social behaviors (which are the basic ingredients for natural intelligence reasoning, collaboration and communication among participants) for addressing wicked problems, as espoused by Rittel. We can also use it to design real-time multi-agent systems. Thus, it is fitting to use Brahms for distributed collaborative tactical planning. This paper borrows from Brahms for discussing the design of the generic architecture.

MISSION AND MEANS FRAMEWORK MODEL

The Missions and Means Framework (MMF) Model recently proposed by Dietz et al. [Dietz et al. May 9 2006], Figure 3, is a structure for explicitly specifying the military mission and for quantitatively evaluating the mission utility of alternative war-fighting Doctrine, Organization, Training, Material, Leadership, Personnel, Facilities (DOTMLPF), Services and products. Its objective is to provide a framework to help the warfighter, engineer, and comptroller specify a common understanding of military operations, systems, and information, and to provide quantitative mission assessment of alternative planning solutions. It provides a disciplined process to explicitly specify the mission, allocate means, and assess mission accomplishment. Furthermore Dietz et al. assert that we can adapt the MMF Model for collaborative tactical planning involving coalition forces and including friendly adversaries such as in Tall Afar and Al Anbar Province counterinsurgency operations. More importantly, the MMF Model approach to specifying the common semantics and syntax of the framework forms the basis for the complex process of decomposition of battlefield operations into atomic elements, specifying the relationships between those elements, and recomposing them into the basic components of simulation construction for collaborative planning [Watkins et al.]. Thus, it is fitting to use it for designing the generic high-level collaborative tactical planning architecture. A brief overview of the MMF Model is essential.

According to Dietz et al., the MMF Data Model begins with the creation of two fundamental entities at each of the seven levels of the framework as shown in Figure 3. Levels 5 through 7 characterize the *mission* portion of the MMF, while Levels 1 through 4 are considered the *means* portion of the framework [Watkins et al.]. Here the term *"means"* include all resources and actions taken in pursuit of the *missions* and their objectives. For example, the units or components tasked, how they are organized, and the strategies, operations, and task decomposition decisions are all considered part of the *means* to achieve the ends associated with the *mission*. At each echelon in a task-organized chain of command, the commander at that echelon works with some factors that are externally imposed and others that are at the commander's discretion. According to Dietz et al., Level 7 (Purpose and Mission factors), Level 6 (Context and Environment factors), and Level 5 (Index and Location/Time factors) represent the externally imposed factors by the central commander. These levels represent the static factors that are outside the span of control of the commander at that echelon. The own forces: Level 1 (Interaction and Effect), Level 2 (Component and Force), Level 3 (Function and Capability), Level 4 (Task and Operation) (and supporting operators) are considered dynamic and under the span of control of the own force commander at that echelon. The same is true with opposing force commander [Watkins et al.]. In addition to the levels described above, the MMF includes the following four *transformational operators* which capture the dynamic relationships that exist between levels [Watkins et al.]: $\mathbf{O_{1,2}x}$ transforms **Level-1** interaction specifications into **Level-2** component states; $\mathbf{O_{2,3}x}$ transforms **Level-2** component states into **Level-3** functional performance; $\mathbf{O_{3,4}x}$ transforms **Level-3** functional performance into **Level-4** task effectiveness; and $\mathbf{O_{4,1}x}$ transforms **Level-4** task effectiveness into **Level-1** interaction conditions. The "x" postscript in each of the designations above refers to the "**S**" or "**E**" operator.

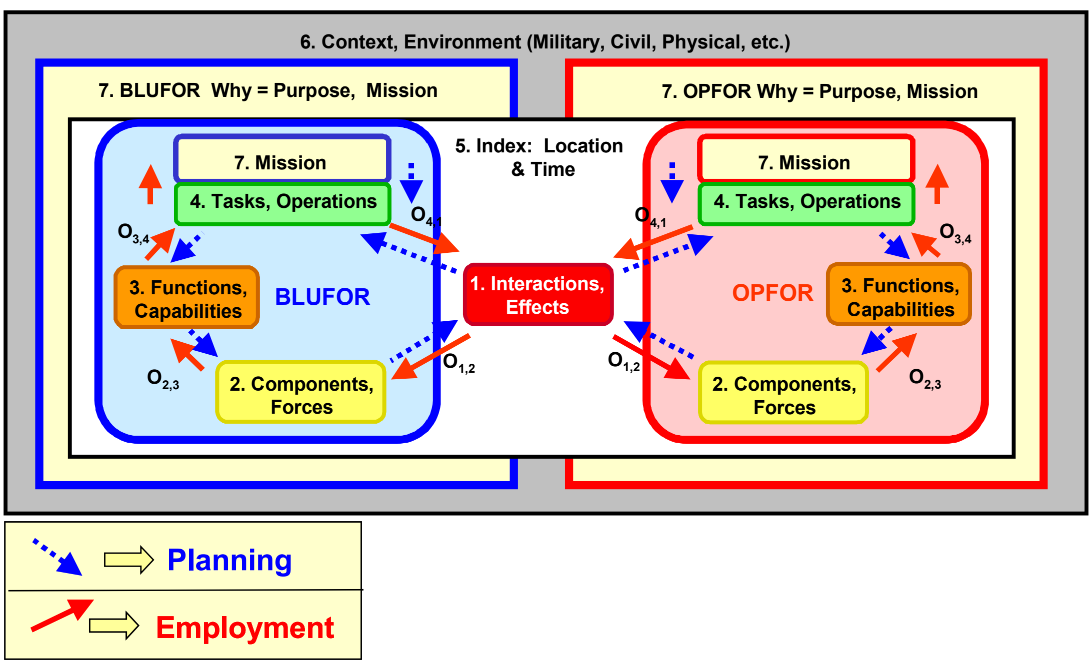

Figure 3. Missions and Means Framework [Dietz et al. May 9 2006].

The MMF has two distinct versions of each *transformational operator*. **Synthesis** (S-suffix) is the top-down planning (blue arrows in Figure 3) and decision-making process that the warfighters use to create, define, and design a military evolution to meet mission requirements [Watkins et al.]. **Employment** (E-suffix) is the bottom-up execution and adjudication of actual outcomes (red arrows in Figure 3) when own and opposing missions/means collide in the battlespace [Watkins et al.]. Please note in Net-Centric environment, planning and execution occur concurrently [Alberts et al. 2007]. Synthesis and Employment operators are not mathematical inverses. Obviously, the processes and procedures used to design a course of action are not the same as those used to execute it [Sheehan et al. 2003]. The MMF has two names for the mission content specified in each level—the *"stocking"* perspective and the *"assembly"* perspective, Figures 6 and 7. In the **stocking** perspective, when the MMF names, records, and references content, the organization within the level is an orthogonal decomposition into **homogeneous** collections of similar content, and uses the first term listed above in the listing of levels. For example, at Level 7, we use Purpose, as the first term to list Level 7, Figure 6. Similarly at Level 6, we use Context to list Level 6, and for Level 5 Index to list Level 5, etc., Figure 6, [Watkins et al.]. In the **assembly** perspective, the MMF content description applies a decomposition of **heterogeneous** packages of diverse content and uses the second term listed above [for example, Mission (Level 7), Environment (Level 6), etc., Figure 3]. For example, a combined arms team or an aviation strike package would each be specified as *forces* in the *assembly* perspective of Level 2 (Figure 7) [Watkins et al.]. Figure 4 shows the details of MMF formal process diagram for designing planning and execution [Dietz et al. May 9 2006]. Steps 1 to 10 associate with the construction of the planning models, and Steps 11 to 15, associate with the testing the plans for how well they would work during execution. Again in Net-Centric environment, planning and execution occur concurrently [Alberts et al 2007]. We will borrow from Figure 4 to discuss the design of the generic collaborative tactical planning architecture.

GENERIC ARCHITECTURE DESIGN FOR COLLABORATIVE PLANNING

Much confusion exists about the planning processes, and the systems-of-systems (SoS) infrastructure (C4ISR SoS), or the info-structure that supports collaborative tactical planning. When we examine the NCW value chain model [Alberts et al. June 2002; Garstka et al. June 2004], we readily note that we should first create the C4ISR SoS, before embarking on any real-time planning system. The primary reason is that we cannot achieve distributed collaborative tactical planning without the networks and the processes to rapidly transmit data and information among the participants in a dynamic battlefield environment. Alberts et al. have emphasized that we can apply the principles of the ***Power To The Edge*** in two ways:

- Design and architecture of systems-of-systems
- C2 (or Organization and management of work)

According to Albert et al. when the ***Power to the Edge*** is fully applied to the design and management of a mission capability package (MCP), the result will be an instantiation of the tenets of NCW [Alberts et al. 2003]. When the ***Power to the Edge*** is applied to an organization and its processes, the result will be an edge organization [Alberts et al. 2003]. When the ***Power to the Edge*** is fully applied to systems architectures, the result will be an edge info-structure, which has the characteristics of DoD's future Global Information Grid [Alberts et al. 2003]. Despite significant contribution of the ***Edge*** concepts to understanding the importance of integrated agile SoS, the authors did not discuss how to design agile info-structure--re-configurable C4ISR value systems--the SoS infrastructure to support the distributed collaborative tactical planning. Using the principles of ***Power to the Edge***, the previous work of Nyamekye has addressed the design of the info-structure [Nyamekye June 2007; Nyamekye June 2008]. Borrowing from the most recent work of Nyamekye [Nyamekye June 2008] for the C4ISR info-structure, Figure 5 shows the generic architecture for a distributed collaborative planning, on the battlefield.

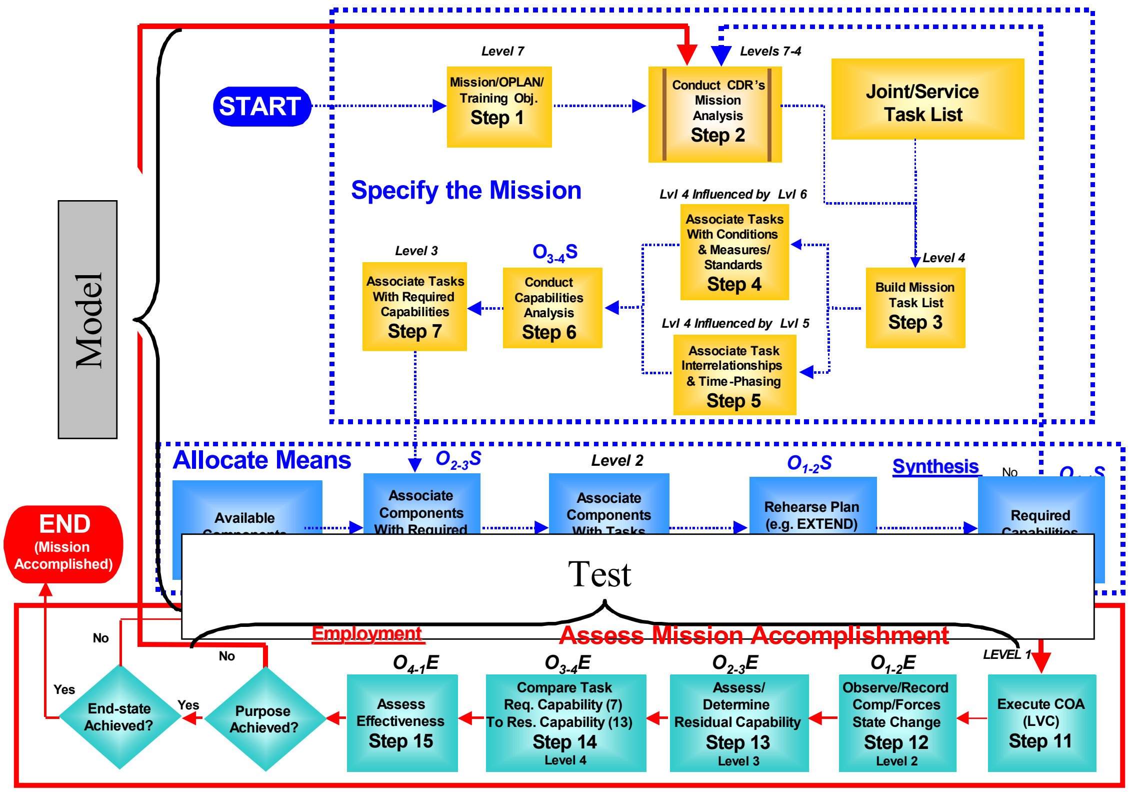

Figure 4. The MMF Formal Process Diagram [Dietz et al. May 9 2006].

The organic assets (Figure 5) represent all the resources that belong to the participants, for example, vehicles, weapons or supplies [Alberts et al. 2007]. The non-organic assets (Figure 5) represent the resources that do not belong to the participants, for example access to roads, or bridges [Alberts et al. 2007]. They typically belong to the host nation. The friendly adversaries represent the former insurgents who were the former enemies to friendly forces, but have decided to join hands with the friendly forces to defeat the bad guys. The non-governmental entities represent the private organizations and others, such as the Red Cross. Please notice that we have used Compendium to create the multi-media data source, which can be battlespace picture, threats, weather, and so on. The data sources are Services in Net-Centric environment. Brahms represents multi-agent business process execution language (MABPEL) [Nyamekye June 2008]. Agent 1 feeds battlespace information to Brahms, which shares it with other agents. The agents then communicate and collaborate through Brahms to design the collaborative tactical planning, through Compendium as IBIS. Using the MMF Model, the agents collaborate and communicate among themselves to design the collaborative tactical planning. To create the MMF Model, the agents must first construct the relationship between entities at each level first. Then using the MMF formal process diagrams (Figure 4), they can create the planning and execution models collaboratively, to achieve Position 4 in the Planning Maturity Models, Figure 1. The output of the planning models will then be the actual plans for testing (Figure 4), as discussed earlier [Alberts et al. 2007]. For simplicity, we have shown the design of the relationships between entities at each level and omitted the details for creating the plans and testing the plans. Please note that Brahms models and tests the tactical plans concurrently.

In Compendium we represent ideas, data sources, arguments, entities (which can represent tables in relational databases) and so on as nodes. Also, we can use a Map node to contain other nodes, and a List node to contain a list of nodes of interest to the participants. Consider Levels 5 to 7, Figure 6 and Levels 1 to 4, Figure 7. At Level 7, we create a Map node to represent Level 7. Please see Figure 8 for the nodes representing Levels 1 to 7. Within Level 7 Map node, we create Map nodes to represent the MISSION and PURPOSE, respectively. The arrow from "MISSION" node to "PURPOSE" node indicates that each MISSION is associated with (comes from) with many "PURPOSES".

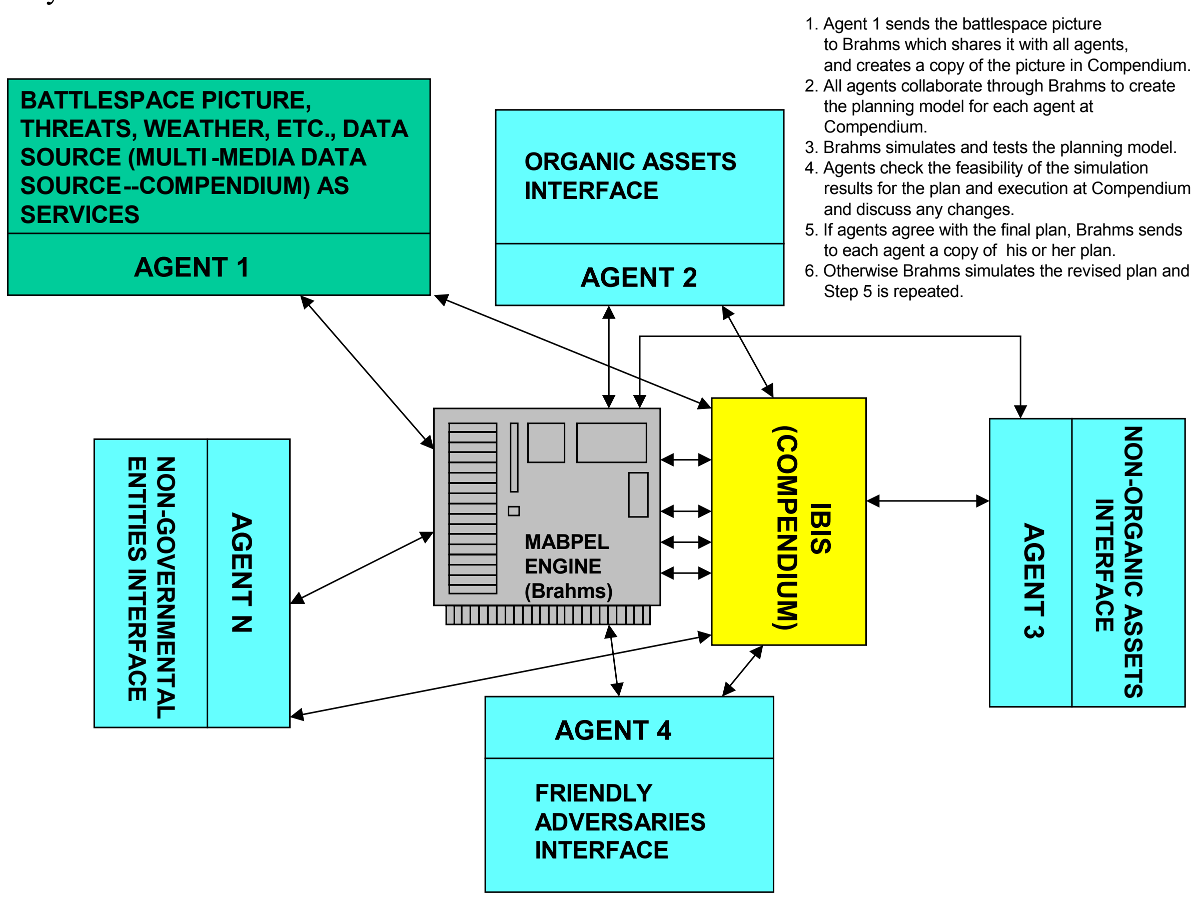

Figure 5. Generic Architecture of Collaborative Tactical Planning, Based on Nyamekye's Recent Work for Designing Integrated C4ISR Systems-of-Systems Architecture--C4ISR Info-Structure [Nyamekye June 2008].

Figure 9 shows the one-to-many relationship between MISSION node and the PURPOSE node. Figure 8 shows such a relationship for Level 7. Consider Level 5, with four entities, (in Figure 6). The four entities correspond to "4" shown on the left of Level 5 node (Figure 8). Figure 10 shows the four nodes inside Level 5 node, and the relationships among the four nodes associated with Level 5 (in Figure 10). Also, please notice "2" on the right of the Level 5 node (Figure 8). It represents that Level 5 node appears in the two nodes. That is, Level 5 node appears in the main Map Window (IABSRI's Home Window) and in the "LEVELS LIST" node, respectively. The LEVELS LIST contains the list of Levels 1 to 7 nodes. The "2" (Level 5 node in Figure 8) also means that when we update Level 5 node, we will also dynamically update Level 5 node in the main Map Window and in the LEVELS LIST node. This concept is very intriguing, because it means that we can use the same node (for example organic asset) in different battlefield mission scenarios. When we update that node all the other nodes that have that node will also receive the update. More importantly, each node has a unique identification number and a unique name. With such an approach we can achieve semantic interoperability--an important requirement for info-structure design for collaborative tactical planning in Net-Centric environment--in IBIS since the participants would agree on standard names for nodes. Noll et al. [Noll et al. 1999] have also noted such an approach for designing information-based distributed enterprise SoS involving collaboration and communication among entities at different geographical areas.

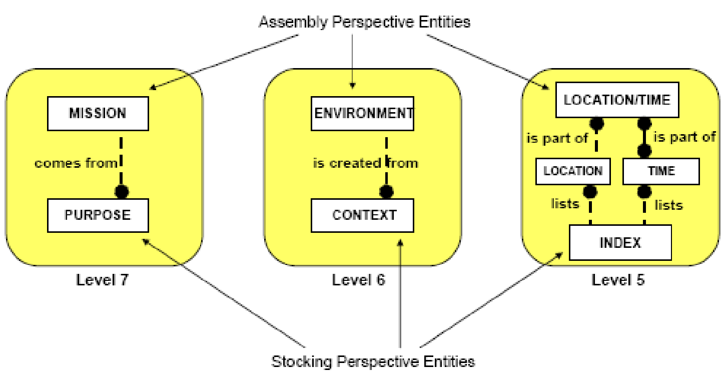

Figure 6. Relationships Between Entities at Each Level for Levels 5-7 [Watkins et al.].

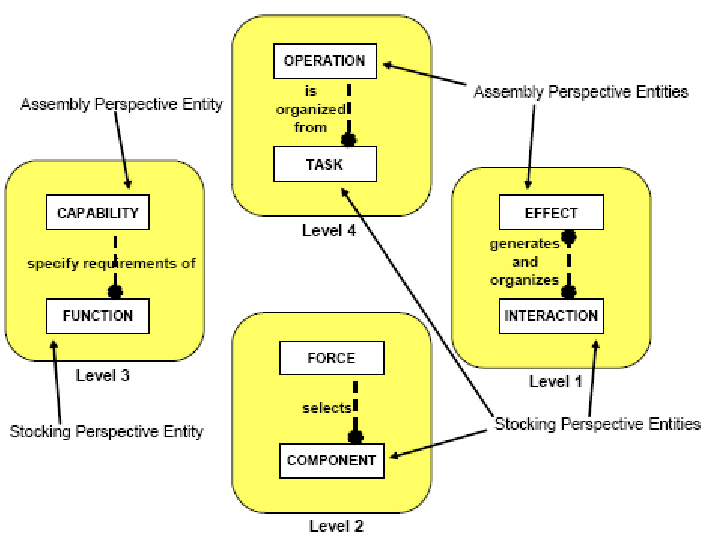

Figure 7. Relationships Between Entities at Each Level for Levels 1-4 [Watkins et al.].

After designing the nodes for Levels 1 to 7, the agents then use the MMF formal process diagram, Figure 4, to complete the planning and execution collaboratively. For simplicity we have omitted details of such an effort. At each step -- from Steps 1 to 10 in Figure 4--the agents can request Brahms to validate the model. Brahms can also assess Steps 11 to 15 to ensure that the purpose and the end-state of the MISSION are achieved. Please note in Figure 4 that Level 1 represents the Command Intent. Please also note that Brahms dynamically updates the models as information changes in Compendium or as new battlespace picture arrives from Agent 1. Using the Design Navigation Method or AXIOM 2, Brahms also tests the performance of different plans (Figure 4) and selects the plan that will achieve the best overall mission within the range of the design parameters (operating variables) due to uncertainties on the battlefield. A brief overview of the Design Navigation Method is essential.

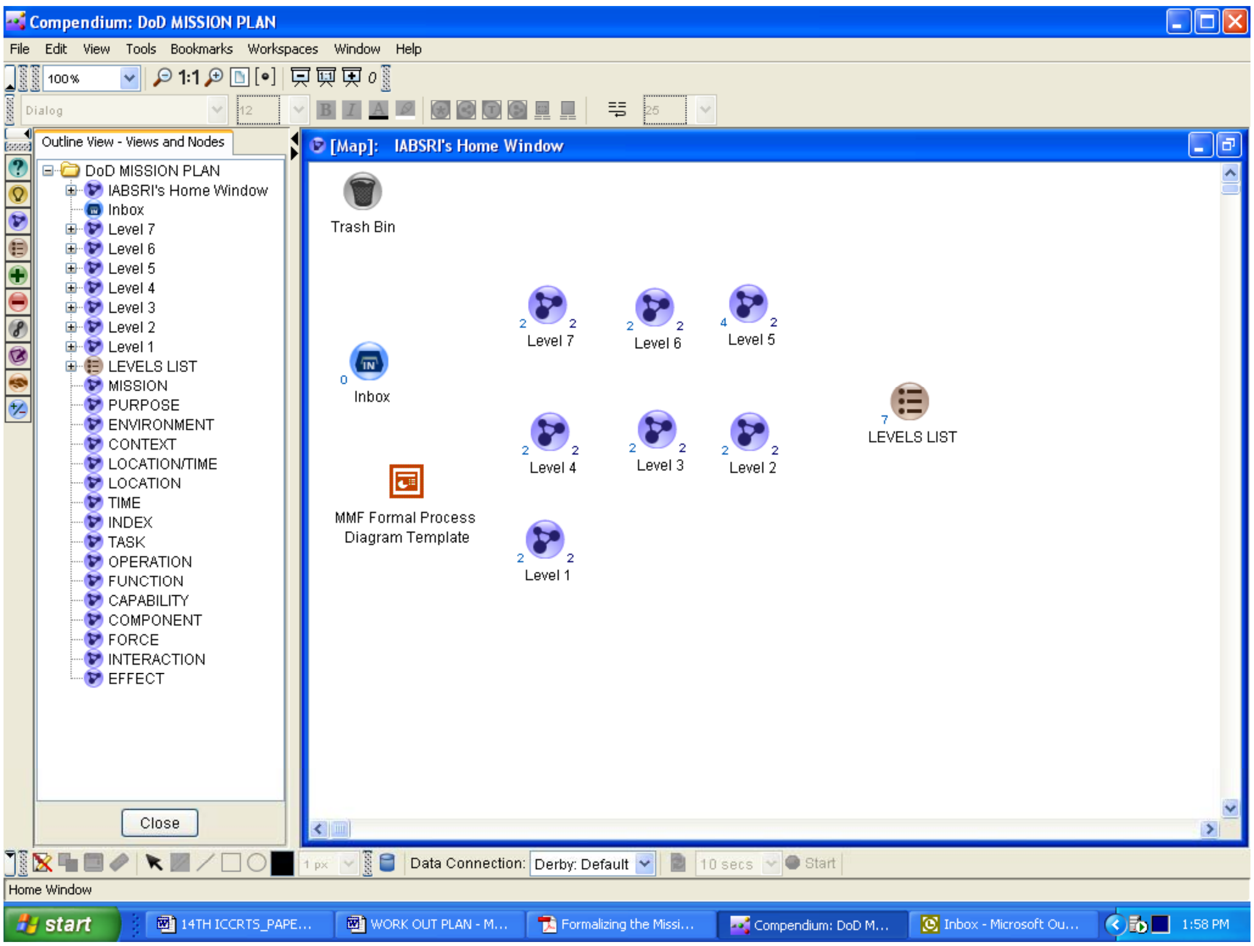

Figure 8. Nodes Representing Levels 1 To 7.

Nakazawa [Nakazawa 2001] has nicely discussed the approach for evaluating the total minimum information content (AXIOM 2) for several functional requirements, FRs, for example, tasks to execute the battlefield plans, or planning time. He calls the overall design concept, Design Navigation Method. For convenience, we will use the symbols from his work. The steps are as follows. In Figure 11, the $A1, A2, \ldots Ap$ represent the different levels of a design parameter, DP (such as environmental factors, weather conditions), and the E represents the functional requirement, FR. Please note that the functional requirements (FRs) correspond to the measures of merit (MOM)--to evaluate the different plans [Alberts et al. 2007]--and the design parameters (DPs) correspond to the variables or elements that we can vary to achieve FRs. First we vary the design parameters to take on the values, $A1, A2, \ldots Ap$, each of which yields multiple (n) experimental or simulation data, on a given FR, or E. These data will show a scattered distribution. For the (n) data points gathered for $A1$, the mean, m, and the standard deviation σ (square root of unbiased variance) are obtained. The two points, representing $m \pm k\sigma$, are then plotted above $A1$, as we can see in Figure 11. The k is the safety factor. The two points will correspond to the upper and lower limits of the system range, for example the performance range of the Quality of Command [Alberts et al. 2007]. We then repeat the same method for the upper and lower limits for the rest of the parameter values, $A2$, ..., Ap.

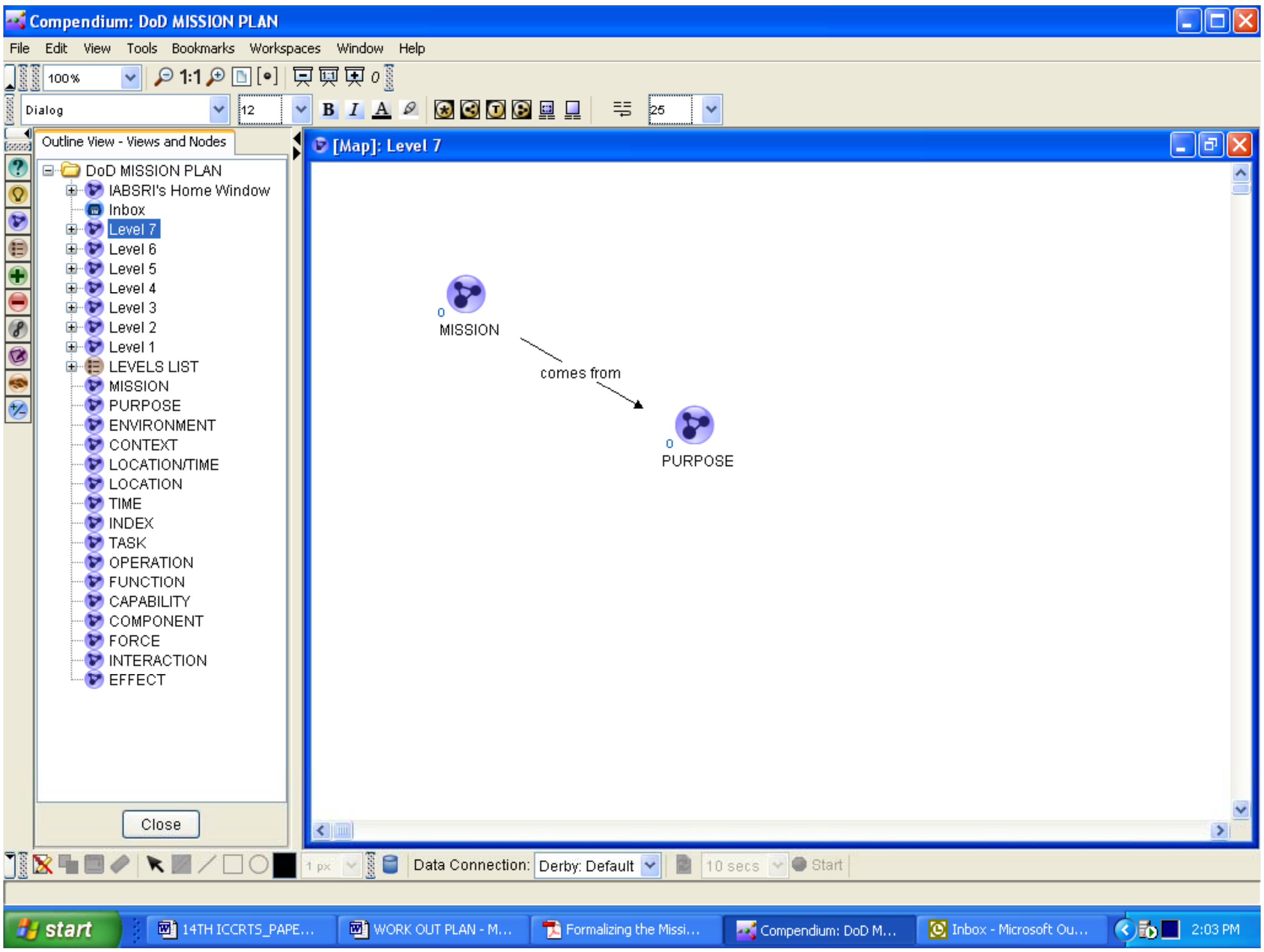

Figure 9. One-To-Many Relationship Between MISSION node and the PURPOSE Node.

We then fit a line, a quadratic, or other curve through the points representing the upper limits, while those in the lower limits are fitted with another curve. We can now enter the design range (the range of a performance measure, such as the range of acceptable planning time established by the central commander), Ed for the upper value and the lower value, on the same graph, as we can see in Figure 11. We can now establish the common range (the overlap of design range with system range) for any design parameter value between $A1$ and Ap. Using the minimum information content model [Nyamekye June 2008], we find the information content (function error) for each design parameter value, between $A1$ and Ap. For example, at $A1$, we find the information content (function error). Similarly, we obtain the information content (function error) for $A2$ and Ap, respectively. We go through the entire steps again for the other functional requirements, for example Plan Quality [Alberts et al. 2007], and sum up the information contents (function errors) at each parameter value; plot the information content (function error) values as a function of the design parameter values on a graph, to obtain the total information content (total function error) curve. Figure 12 exhibits the total information content (total function error) curve. Please note that the total minimum information content (total function error) value occurs at Aop. However, within $A1$ and Ap, the total minimum information content (total function error) is acceptable, an approach which Alberts et al. [Alberts et al. 2003] has suggested for evaluating Net-Centric Warfare Model, due to uncertainties on the battlefield. Table 1 shows the experimental design for testing the plans (Figure 4) created from collaborative planning. Brahms simulates the plan model and tests the plans concurrently.

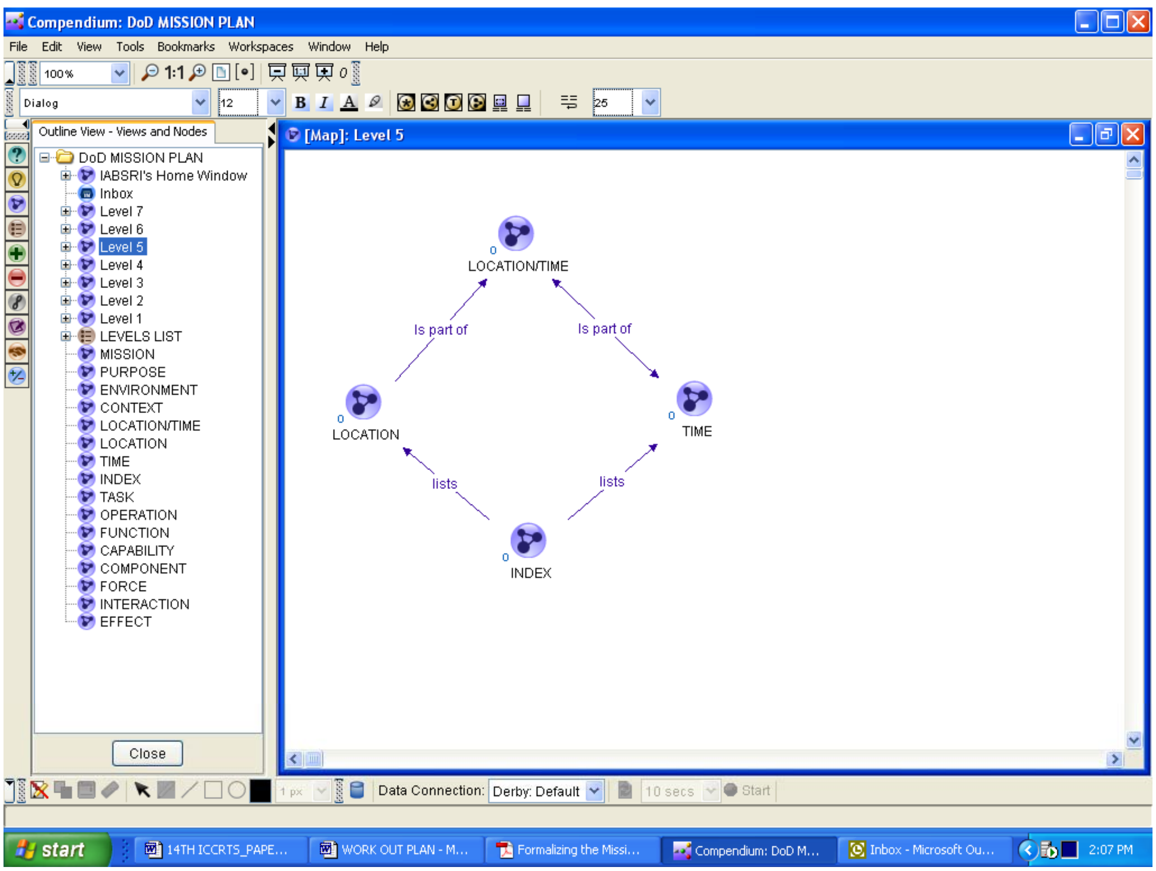

Figure 10. The Relationships Among The Four Nodes Associated With Level 5 Node (from Figure 8).

Nakazawa has shown such steps for many design parameters (especially when the design parameters exhibit interaction effects as in typical experimental designs) and many functional requirements. For convenience, we will omit the details of the discussion. Nyamekye has also recently used it to for evaluating network design for C4ISR SoS [Nyamekye June 2008] info-structure.

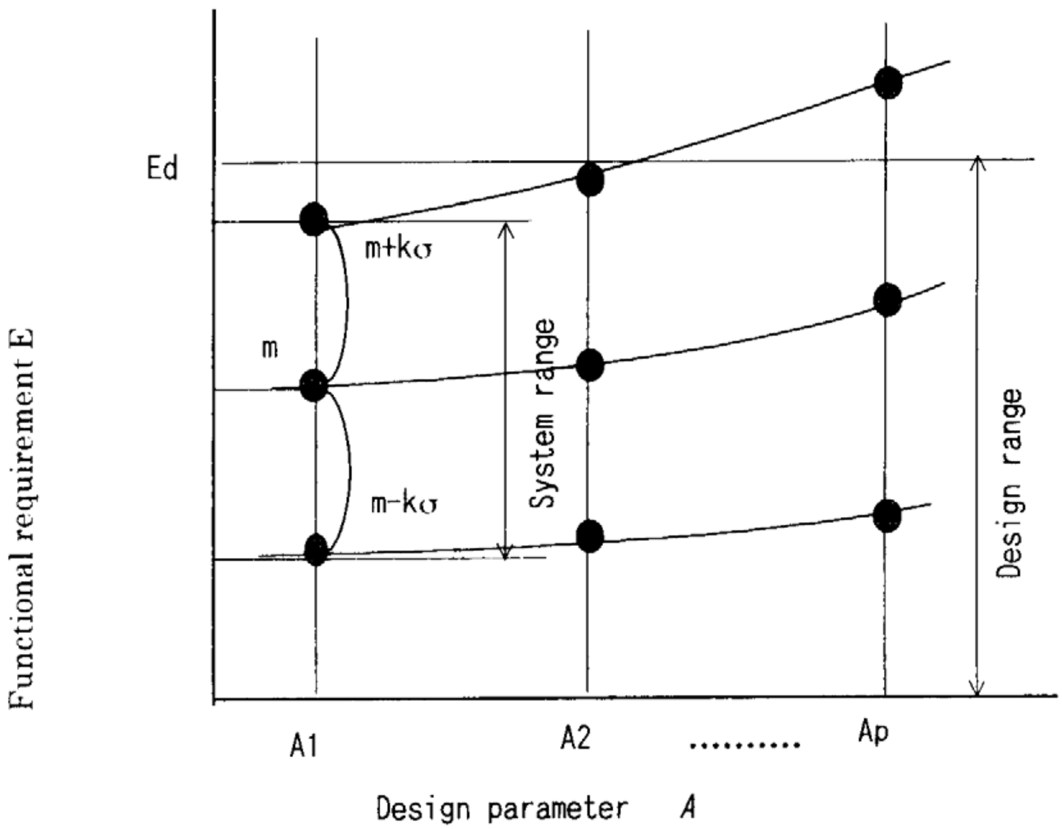

Figure 11. System Range of Design Parameter A for Functional Requirement [Nakazawa 2001].

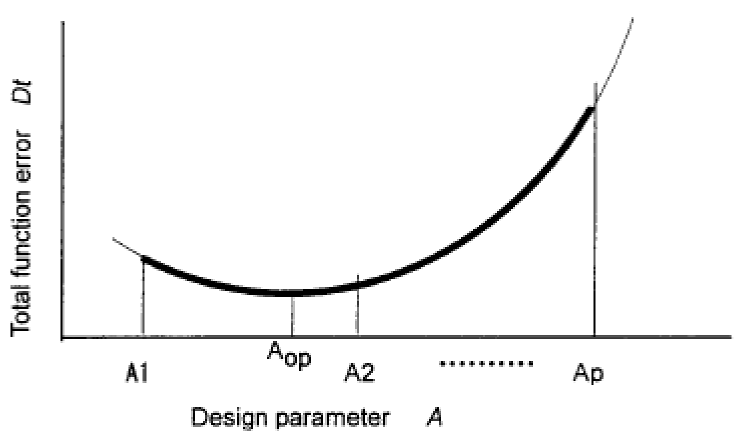

Figure 12. Total Information Content (Function Error Curve) [Nakazawa 2001].

NO	DESIGN PARAMETERS (DPs)				EXPERIMENTAL OR SIMULATION RESULTS FOR FUNCTIONAL REQUIREMENTS (FRs)		
	A	B	C	D	E	F	G
1	A1	B1	C1	D1	E1	F1	G1
2	A1	B2	C2	D2	E2	F2	G2
3	A1	B3	C3	D3	E3	F3	G3
4	A2	B1	C1	D1	E1	F1	G1
5	A2	B2	C2	D2	E2	F2	G2
6	A2	B3	C3	D3	E3	F3	G3
7	A3	B1	C1	D1	E1	F1	G1
8	A3	B2	C2	D2	E2	F2	G2
9	A3	B3	C3	D3	E3	F3	G3

Table 1. Orthogonal Table For Experimental Design for Evaluating the Collaborative Planning [Nakazawa 2001.] The functional requirements (FRs) correspond to the measures-of-merit (MOM) [Alberts et al. 2007]. Please see Figure 4 for testing the plans.

CONCLUSIONS

Using the Issue-Based Information Systems (IBIS) concepts with Compendium as an example of a generic IBIS for solving wicked problems typical in collaborative tactical planning, NASA Brahms multi-agent oriented modeling and simulation language as a generic language, and Missions and Means Framework Model, the paper discusses the design of a generic high-level approach for distributed collaborated tactical planning--Position 4 in integrated Planning Maturity Models, Figure 1. The paper then borrows from Design Navigation Method, a design scientific method that uses minimum information content theory (AXIOM 2 of Axiomatic Design) to discuss evaluating the test plans. The concepts from the paper can be adapted to designing any ad hoc distributed collaborative tactical planning system that involves many stakeholders with different agendas, for example in humanitarian assistance efforts during natural disasters such as Katrina and Tsunami. Such mission planning involves only specifying the Unity of Command (for example from United Nations) to each participating organization. Each participating organization then develops and tests the plan to fulfill the Unity of Purpose. No hierarchical Command and Control structure occurs in such mission planning scenarios. We can use it for planning for any Edge-Based organization [Sviokla November 11 2008]. More importantly, we can use the concepts to dynamically create adaptive distributed collaborative tactical planning systems for building ad hoc value ecosystems such as the supply chains for the construction industry, or even intelligent adaptive collaborative tactical planning for distributed energy infrastructure, which adapts itself on-demand to changing energy requirements of the customers, thereby achieving an overall energy efficiency of the ecosystem.

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AUTHOR BIOGRAPHIES

Dr Kofi Nyamekye is the President and Chief Executive Officer of Integrated Activity-Based Simulation Research, Incorporated, formerly known as Nyamekye Research & Consulting (NRC). Through his career, he has developed the educational, research and industrial experience to design and operate any manufacturing production system. As an educator (a former college professor) and a researcher, Dr. Nyamekye has published extensive articles on the design and operation of Cellular Manufacturing Production Systems and Simulation and Modeling of the Traditional Manufacturing Processes. Dr. Nyamekye has received many awards, among them the *1994 Educator of the Year Award from the St. Louis Society of Manufacturing Engineers Chapter 17 and the 1996 Best Paper Award selected by the Engineering Division of the American Foundrymen's Society.*

Under a large research grant from the U.S. Department of Energy, he pioneered a computer simulation model for the mold failure of the permanent mold casting process. The model will play an essential part as a federate in a distributed enterprise simulation model for automobile manufacturing supply chain federations.

Dr. Nyamekye is a member of the National Institute of Standards and Technology (NIST) International Consortium of Research Scientists called the IMS MISSION. The goal of the MISSION is to integrate and utilize new, knowledge-aware, technologies of distributed persistent data management, as well as conventional methods and tools in various enterprise domains, to meet the needs of globally distributed modeling and simulation. Under a grant from NIST, Dr. Nyamekye has established the methodology for designing Activity-Based Simulation (ABS) System as a federate in the NIST distributed enterprise simulation model for the NIST IMS MISSION. The NIST federation uses the High Level Architecture Run-Time Infrastructure (HLA RTI) architecture. The ABS uses the entity relationship (E-R) modeling technique for designing an Activity-Based Costing model with input data from the simulation federates for supply chain optimization.

Recent emphasis on Activity-Based Methodology by MITRE and Lockheed-Martin, for Service-based simulation of NCW and emphasis on Activity-Based Simulation by the Navy Modeling and Simulation Office [NMSO, http://nmso.navy.mil/glossary.cfm], have made Activity-Based Simulation the essential concept for dynamic simulation and optimization of Service-Oriented Architecture (SOA). Dr. Nyamekye has extensive prior experience as a senior research scientist in modeling and simulation of *complex adaptive distributed enterprise systems* for Boeing's Army Future Combat Systems. Dr. Nyamekye has previously published with other investigators the concepts for designing information system architecture for the wired battlefield. He has also recently established the scientific base for designing re-configurable C4ISR SOS [***Nyamekye June 2007***, http://www.dodccrp.org/events/12th_ICCRTS/CD/iccrts_main.html, ***C2 Technologies & Systems, #220***].

Dr. Nyamekye is also a member of the NIST Simulation Standards Consortium, and American Society for Engineering Education (ASEE). He holds a PhD in Industrial Engineering from Pennsylvania State University, an MS in Mechanical Engineering from Pennsylvania State University, and a BS in Mechanical Engineering from the University of Wisconsin. He can be reached at kofinsoyameye@earthlink.net.

Dr. Sierhuis has been involved with expert systems and knowledge engineering since 1985. His research involves multi-agent systems modeling and simulation of human organizations and social technical systems. He was co-inventor of the Brahms multi-agent modeling and simulation environment, as well as the Compendium methodology for informal modeling of wicked-problems and conversations in facilitated meetings. Dr. Sierhuis is the Co-Lead of the Mission Operations Design and Analysis Tool project funded by NASA Johnson Space Center. He is a Co-Principal Investigator of the Brahms project and also a Co-Principal Investigator and Project Manager for the Mobile Agents project where he led six independent research teams with a total of 49 people in a two-week field test of human-robot teams at the Mars Desert Research Station in the Utah desert from 2002-2006. Dr. Sierhuis has extensive publications on multi-agent modeling and simulation of intelligent systems. He is the author of the book entitled, ***"Modeling and Simulating Work Practice; Brahms: A Multi-agent Modeling and Simulation Language for Work System Analysis and Design," published by PONSEN AND LOOIJEN BV, Vijzelstraat 6-8, 6701 DC Wageningen, The Netherlands, 2001.***

Dr. Sierhuis leads the Collaborative Assistant Systems group at RIACS/USRA located at NASA Ames Research Center. He holds a PhD in Social Science Informatics from the University of Amsterdam, and BS in Engineering with emphasis on Informatics from the Polytechnic University in Hague. He can be reached at Maarten.Sierhuis-1@nasa.gov.

Ron van Hoof is a computer scientist. Currently he works for Perot Systems Government Services at NASA Ames Research Center where his work involves the development of a multi-agent modeling language, simulation environment and real-time agent execution environment used to both simulate and support work practice (BRAHMS). Ron's responsibilities include being the development lead, system architect and software engineer responsible for the Brahms language, Brahms virtual machine, the integration of the Brahms components and to both develop and support the development of Brahms-based distributed agent systems.

Ron van Hoof holds an MS degree in Knowledge Engineering from the University of Middlesex, London, England and a BS degree in Computer Science from the Hoge School West-Brabant in Netherlands. He can be reached at Ronnie.J.VanHoof@nasa.gov.