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Warfighter Decision Making in Complex Endeavors: Using Purposeful Agents and Reflexive Game Theory

Suggested Topics: Collaboration, Shared Awareness, and Decision Making; Modeling and Simulation; Concepts, Theory, and Policy

Name of Author: Kofi Nyamekye, Ph.D.

Point of Contact: Kofi Nyamekye, PhD

Name of Organization: Integrated Activity-Based Simulation Research, Inc.

Complete Address: 1919 South Grand Boulevard, Suite 412, Saint Louis, MO 63104

Telephone: 314-704-7964

E-mail Address: kofinsoyameye@earthlink.net

ABSTRACT

This paper discusses an emerging and powerful scientific approach -- Reflexive Game Theory (RGT) – for *choice or decision making*, for the Warfighter or Small Unit (SU) leader, in *complex endeavors*. The paper emphasizes two deficiencies in the classical game theory, namely: irrational risk a player is inclined to make, and the lack of cognitive model in the classical decision making function. Using the recent report of National Research Council study on improving the decision making ability of the SU leader, as the scientific linchpin for this paper, the author has discussed the scientific approach for using RGT for *choice or decision making*, which includes the mental model of the Warfighter in *complex endeavors*. Using AXIOM 2 of Axiomatic Design and Design Navigation Method, the author has discussed experimental design to validate the predicted choices and the selection of "realizable" alternatives when much uncertainty, in the operating environment, can influence the predicted choices and the selection of "realizable" alternatives. The paper emphasizes Multi-Threaded Missions and Means Framework (MTMMF) as the basis for defining the set of actions or Functions, Capabilities – Level-3 in MTMMF -- for choice prediction and choice selection. The Libyan conflict serves as a case study for the RGT.

INTRODUCTION

The recent emphasis on Warfighter's *choice or decision making*, especially in *complex endeavors* cannot be overemphasized. We will shortly discuss complex endeavors. The importance of the Warfighter's *choice or decision making* in irregular warfare (IW), was recently echoed in a recent report entitled, "*Improving the Decision Making Abilities of Small Unit Leaders,"* [National Research Council (NRC) July 2012]. Among several of NRC's findings and recommendations, the following noteworthy finding and recommendation deserve attention [National Research Council (NRC) July 2012]:

"FINDING 7: *Established and emerging research in human cognition and decision making is highly relevant to developing approaches and systems that support small unit decision making. Cognitive psychology can provide significant guidance in developing technologies that support the decision maker, including approaches to information integration, tactical decision aids, and physiological monitoring and augmented cognition. However, technologies that do not incorporate human-centered design methods—such as those of cognitive systems engineering—may not generate useful and usable in-theater decision aids for the small unit leader. Lastly, the emerging field of cognitive neuroscience may have significant potential for developing the understanding of the fundamental neurophysiological mechanisms underlying human decision making. Although research in this area is very new, over the next few decades it may generate a fundamental paradigm change in scientific approaches to understanding human perception, sensemaking, and decision making.*"

"RECOMMENDATION 7: *Continue to invest in and leverage promising areas of science and technology research in the near term, midterm, and far term to enhance the decision making performance of small unit leaders."*

In that same report, the NRC made a very intriguing statement about each US Marines, becoming a "strategic corporal", with the responsibility in *tactical choice or decision making* as a commander in one instance, and as a local tribal leader in another instance – for resolving tribal disputes among indigenous people. A direct quotation from the NRC's report attests to this:

In assessing the posture of the Marine Corps before the U.S. Senate Armed Services Committee in 1998, General Krulak acknowledged a shift from nation state warfare to complex civil conflict when he described the future of conflict not as " 'son of Desert Storm'; it will be the 'stepchild of Chechnya.' "Krulak [Krulak February 5 1998] presciently recognized that in these environments, decisions taken at the level of the small unit can have unforeseen implications: "In the 21st Century, our individual Marines will increasingly operate with sophisticated technology and will be required to make tactical and moral decisions with potentially strategic consequences." Moreover, Krulak [Krulak February 5 1998] pointed out, even decisions taken at the lowest level of rank of the Marines were likely to be "subject to the harsh scrutiny of both the media and the court of public opinion," as new communications technologies facilitated the rapid dissemination of information to an international audience. Whether we like it or not, Krulak [Krulak 1999] argued, the United States is entering the era of the "strategic corporal," when individual Marines become the "most conspicuous symbol of American foreign policy. . . . [Their] actions will directly impact the outcome of the larger operation. [Krulak 1999]"

The implication of these statements is that because the Warfighter is continuously shifting his or her cognitive system between combat operations and complex civil service, the same Warfighter might at one instance make a decision of how to engage an enemy without collateral damage, while in another instance he or she might decide how to settle a dispute between two indigenous people, whom the Warfighter is protecting against the insurgents. For *complex endeavors which involve the Warfighter collaborating with participants with different sociocultural backgrounds on different missions*, and whose decision may be influenced by such diversity of participants, the Warfighter's *choice or decision making*, becomes extremely challenging. A discussion of the fundamental concepts of *complex endeavors* is essential before proceeding further. According to Alberts et al. [Alberts et al. 2007], *complex endeavors*, refers to understandings that have one or more of the following undertakings:

1. *The number and diversity of the participants is such that*
   a. *there are multiple interdependent "chains of command,"*
   b. *the objective functions of the participants conflict with one another or their components have significantly different weights, or*
   c. *the participants' perceptions of the situation differ in important ways; and*
2. *The effects space spans multiple domains and there is*
   a. *a lack of understanding of networked cause and effect relationships, and*
   b. *an inability to predict effects that are likely to arise from alternative courses of action.*

Despite the significance of the Warfighter's *choice or decision making* in IW, the scientific model for predicting the Warfighter's choices and the selection of the choices is an emerging scientific endeavor. Of particular importance is the effect of uncertainty and complexity on the battlefield that might influence the scientific model for predicting the choices and the selection of choices. Consider the scenario when a unit leader receives the common operating picture (COP) depicting an emerging insurgents' attack, from a specified location at a certain instant of time. Suppose the insurgents have used some deceptive measure such as actually creating a wedding-type celebration scenario where some other local tribesmen shoot into the air as celebrating some wedding but the actual insurgents are in some other location. Under such a condition of battlefield uncertainty, the COP would not only provide the false location of the actual insurgents to the unit leader but such battlefield uncertainty in irregular warfare would cause the unit leader to choose the set of actions and weapon system to attack the local tribesmen who are not the actual insurgents. The actual insurgents would exploit any tragedy from the attack to the news media for war propaganda – "*we told you that they (the platoon leader and the platoon) are killing our innocent people*." Thus, we need the scientific model that should not only accurately predict Warfighter's choices and the selection of the correct Warfighter's choices but also the scientific model should include the effect of the battlefield uncertainty on the choice prediction and choice selection. More importantly the scientific model must include the *mental model* of the Warfighter. The Reflexive Game Theory (RGT) [Lefebvre 2010], as a unique example of modeling purposeful individuals [Ackoff et al. 2006] as purposeful agents, addresses such needs.

In the subsequent sections we will first discuss an overview of RGT, and purposeful individuals and purposeful agents, followed by the mathematical model of RGT in *choice or decision making* of a subject – e.g. the Warfighter. We will borrow from the previous work of Nyamekye et al. [Nyamekye et al. 2009] on Missions and Means Framework (MMF) and Multi-Threaded Missions and Means Framework (MTMMF) [Nyamekye 2010] as the technical basis for defining the functions for choice prediction and choice selection. We will discuss the effect of uncertainty and complexity on the choice model and choice selection. Using Axiomatic Design [Suh 1990], Design Navigation Method (DNM) [Nakazawa 2001] and experimental design approach, we will emphasize constructing experimental tests to validate the *predicted choices and the selection of the predicted choices* before the realization of the appropriate set actions from the chosen alternative, followed by the application of the RGT for the Libyan conflict, as an example of *complex endeavors*. Conclusions will then follow.

OVERVIEW OF REFLEXIVE GAME THEORY (RGT), PURPOSEFUL INDIVIDUALS AND PURPOSEFUL AGENTS

From the viewpoint of classical game theory, decision making involves two types of theories, namely: descriptive and prescriptive. The descriptive theory is about <u>choice prediction</u> of a player [Lefebvre 2010], and the prescriptive theory is about the choices the player must make – <u>choice selection</u> from the <u>choice prediction</u>. To minimize the losses of a player, the classical game theory employs max-min decision function for both theories. A major issue with the classical game theory is that a player is inclined to an irrational risk in making a decision – from faulty reasoning process [Lefebvre 2010]. Consequently, we cannot use the classical game theory, when we want to minimize risk in *choice or decision making*. Particularly on the battlefield, where much uncertainty (in the operating environment) could lead to irrational risk in the Warfighter's *choice or decision making*, the classical game theory is inappropriate for decision making. More importantly, the classical game theory does not account for the cognitive system of the subject – e.g. the Warfighter -- in *decision making*. The Reflexive Game Theory (RGT) addresses such deficiencies in *choice or decision making*.

The goal of Reflexive Game Theory (RGT) is to predict the individual choice made by a subject belonging to a group [Lefebvre 2010]. Also, the RGT can predict the influences of other subjects in a group on another subject to make a particular choice [Lefebvre 2010]. We call such an extension of the RGT, *reflexive control* [Lefebvre 2010]. This paper will not address *reflexive control*. Please note that the term subject refers to single individuals or different types of organizations, e.g., military units, political parties, and even states [Lefebvre 2010]. In fact we can think of single individuals or different types of organizations, as participants in *complex endeavors*, as noted before. Though this paper will not deal with *reflexive control*, the concept of *reflexive control* is very intriguing and deserves attention, especially for IW. For example, in IW the friendly forces can send a deceptive message to insurgents to purposely influence the insurgents to make a decision that would benefit the objectives of the friendly forces. The author's future publications will address *reflexive control*, in IW.

Of particular importance is the concept *anti-selfishness principle*, which states as follows [Lefebvre 2010].

While pursuing his own personal goals, the subject may not cause harm to the group he is a member of.

The implication of the *anti-selfishness principle* is that it is unacceptable for a subject to take actions that are harmful to the group to which the group belongs, if even if such actions are advantageous to the subject. For example when an individual such as the Soldier interacts with other Soldiers to execute a mission plan, each Soldier should cooperate in a manner so as not to cause harm to other Soldiers interests in the group as a whole. In IW where the Warfighters may include friendly local tribesmen with different social and cultural values, the *anti-selfishness principle* is essential for successful outcomes of overall mission of the group as a whole.

The term purposeful agent draws from the purposeful individual or system [Ackoff et al. 2006; Lefebvre 2010]. A brief overview of purposeful individual, system or a purposeful agent is essential, before subsequent discussions.

A purposeful individual or system [e.g., a Soldier or system (e.g., a weapon system)] is one that can, not only change its behavior to pursue the same goal -- as conditions in the operating environment change --, but also a purposeful individual or system is one that can choose its own goals and the means by which to pursue the goals [Ackoff et al. 2006]. *A purposeful individual or system thus displays will* [Ackoff et al. 2006.] Please note that a purposeful individual or system can also learn and adapt itself to uncertainties in its environment [Ackoff et al. 2006]. More importantly, the environment of the individual or system cannot choose the goals for the purposeful individual or system! This statement implies that a purposeful individual or system is a PROACTIVE system (as opposed to a simple "Pavlovian" system that just reacts to changes in its surrounding environment.) Only humans or people are purposeful individuals or systems! Thus, Nano-devices, artificial intelligent robots, etc., are not purposeful systems. They emulate purposeful systems. Ackoff et al. [Ackoff et al. 2006] call such systems, multi-goal-seeking individuals or systems. The users -- humans (e.g., the strategic corporal or a small unit (SU) leader) -- of these systems set the goals! ***We define purposeful agents to be agents that can set their own goals and they have the same cognitive capabilities closely resembling those demonstrated by humans. Contrary to the purposeful agents, the traditional agents cannot set their own goals and they lack cognitive capabilities of humans*** [Nyamekye November 2010; Lefebvre 2010]. This is the fundamental difference between the traditional agent and the purposeful agent. In fact North and Macal [North and Macal 2007, Page 102] clearly articulate the *traditional agent* as follows: "*The fundamental features that make something a candidate to be modeled as a traditional agent are the capabilities of the component to make independent decisions, some type of goal to focus the decisions, and the ability of other components to tag or individually identify the component.*" *Unlike the purposeful agent that sets its own goals, the traditional agent must use the goal set by some individual or the user of the system being modeled*. This issue is particularly important because in irregular warfare (IW) the ability of the SU leader to change the goal (on the fly) which may be different from the initial command intent, and predict the new choice of functions, choose the new appropriate set of functions – *alternative* -- from the predicted choice of functions and the weapon systems to attack the enemy, may be critical to the survival of the SU. Of course the higher headquarters would be able to monitor the situation and would know that the SU leader has changed the mission. A direct quotation from Alberts et al. [Alberts et al 2006] attests to such a situation: "*For example, when a military situation becomes urgent (e.g., an ambush at the tactical level, the realization that an adversary has executed an effective deception plan at the operational level and therefore friendly forces are incorrectly positioned), commanders at lower levels will not (under the doctrine of most modern forces) consult with higher headquarters about deviating from the plan or wait for a new plan, but rather take the initiative by making decisions about how their forces will immediately react. They then inform higher headquarters of what has occurred and the actions they are taking and request support so that they can deal with the ongoing challenge. (Of course, in an ideal world, the other parts of the force, including their higher headquarters, would be able to monitor the situation and would know that they had begun to take initiatives.) If these actions take them outside the existing plans or guidance, they will have altered the distribution of decision rights.*"

Because cognitive science is the scientific foundation of RGT, we can say that the "subject" defined within the context of RGT, is also a purposeful agent. Thus, we can use RGT to create new purposeful agent-based systems whose cognitive capabilities closely resemble those of humans. This is precisely ***RECOMMENDATION 7***, which the NRC noted among its several recommendations. It is quite interesting to note that ***RECOMMENDATION 7*** also emphasizes new scientific research endeavor – *cognitive neuroscience* – be pursued to aid the choice or decision making ability of a small unit leader. In fact, prior to the NRC's publication, the author had already proposed such a research idea – *integrated RGT-based purposeful agent and neuroscience* -- through private communication with Lefebvre [Nyamekye and Lefebvre May 8 2012].

MATHEMATICAL MODEL OF REFLEXIVE GAME THEORY (RGT) FOR CHOICE OR DECISION MAKING

Conceptual Representation of a Subject

In RGT we assume that a subject can perform actions $\alpha_1, \alpha_2, ..., \alpha_S, S \geq 1$ [Lefebvre 2010]. Also, we assume that the subject can perform these actions both technically and morally [Lefebvre 2010]. According to Lefebvre, *the relation of preference on the set of actions is not given.* He defines a universal set, as a non-empty set of actions which can be represented as 1. Please note that an empty set contains no elements or actions. The set M of all subsets of the universal set, including an empty set, is the set of alternatives [Lefebvre 2010]. That is, each alternative is a subset of the universal set of actions. The subject's action then consists of choosing an alternative from the set M, and then "realizing" the "choice" [Lefebvre 2010]. When a subject chooses an empty set, it means that he or she refuses to choose any non-empty alternative.

We should emphasize that a subject's choice or decision making depends on the relationships among the group members and the influences that the group members have on the subject [Lefebvre 2010]. We will illustrate this concept and other concepts later. Furthermore, the subject has an *intention* – called *self-influence* --, to choose one or another of the alternatives (set of actions) [Lefebvre 2010]. Also, subjects are non-intentional and international [Lefebvre 2010]. Non-intentional subjects mean that the subjects' intentions are known in advance [Lefebvre 2010]. Intentional subjects mean that subjects' intentions are unknown in advance [Lefebvre 2010]. We will discuss additional concepts of RGT with illustrations later.

To distinguish between the "realization" and "choice", consider a universal set which consists of two sets [Lefebvre 2010]:

α_1 - turn left
α_2 - turn right

We represent the universal set as 1= $\{\alpha_1, \alpha_2\}$, and empty set as 0 = {}. Using the Boolean algebra, we can represent all the possible alternatives (set of actions) as:

1= $\{\alpha_1, \alpha_2\}$, $\{\alpha_1\}$, $\{\alpha_2\}$, 0 = {}

Please note that if the universal set consists of z elements (actions), then we can always find the corresponding Boolean algebra, consisting of all the possible set of actions, including the empty set, from the relationship 2^z (power set) [Lefebvre 2010]. Please note that the set M as previously noted, includes not only the set of all subsets of the universal set, -- 4 in the above case --, but also the set M includes the Boolean operations "+", "**.**", "***negation***", and the relation "***greater or equal***".

The choice of $\{\alpha_1\}$ means that the subject can perform only action α_1, and the choice of $\{\alpha_2\}$, means that he or she can perform only action α_2. Consider the alternative $\{\alpha_1, \alpha_2\}$. Since the subject cannot perform actions α_1 (turn left) and α_2 (turn right) at the same time, alternative $\{\alpha_1, \alpha_2\}$ is not realizable. However, the subject can realize either subset $\{\alpha_1\}$ or subset $\{\alpha_2\}$ after he or she chooses alternative $\{\alpha_1, \alpha_2\}$. The subject does nothing if he or she chooses the empty set 0 = {}.

Choice or Decision Making Equation of a Subject

Equation1 predicts the choices of a subject. Equation 1 is the descriptive model we noted before.

X = AX + B not(X). Equation 1

where X, A, B $\in$ (elements of) M, and A and B do not depend on X [Lefebvre 2010]. Equation 1 has a solution if and only if Equation 2 is valid. The "+" represents the Boolean operator.

$A \supseteq B$ Equation 2

Using Equations 1 and 2 we can find alternatives that the subject can realize. The subject then performs the set of actions, from the chosen alternative, that fulfill *anti-selfishness principle*. This last step is the prescriptive model. Again, to ease with discussion of other concepts, e.g. the mental model, we will discuss them with illustrations later. To discuss the effect of uncertainty and complexity on the *choice or decision making*, we will borrow from the recent work of Nyamekye [Nyamekye August 25 2010; Nyamekye 2011] on Missions and Means Framework (MMF), and the Multi-Threaded Missions and Means Framework (MTMMF). The next section discusses the MMF and MTMMF, with emphasis on SU leader to illustrate the RGT concepts.

MISSIONS AND MEANS FRAMEWORK (MMF) and MTMMF

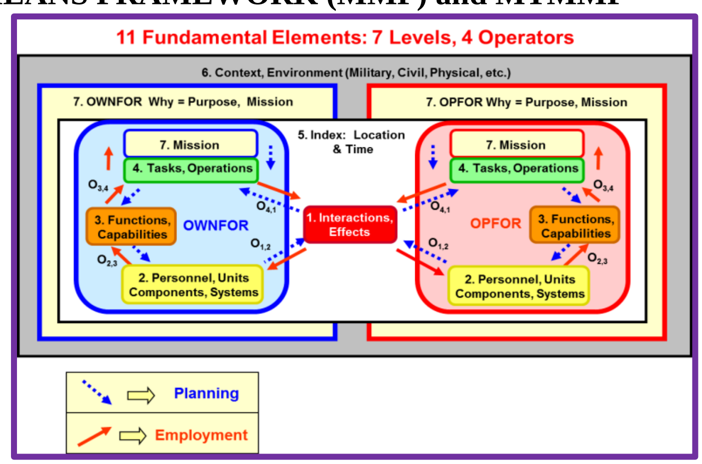

Figure 1. The Basic MMF Model [Deitz et. al. May 2006.]

The basic MMF Model, recently proposed by Deitz et al. [Deitz et al. 2006], Figure 1, 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.

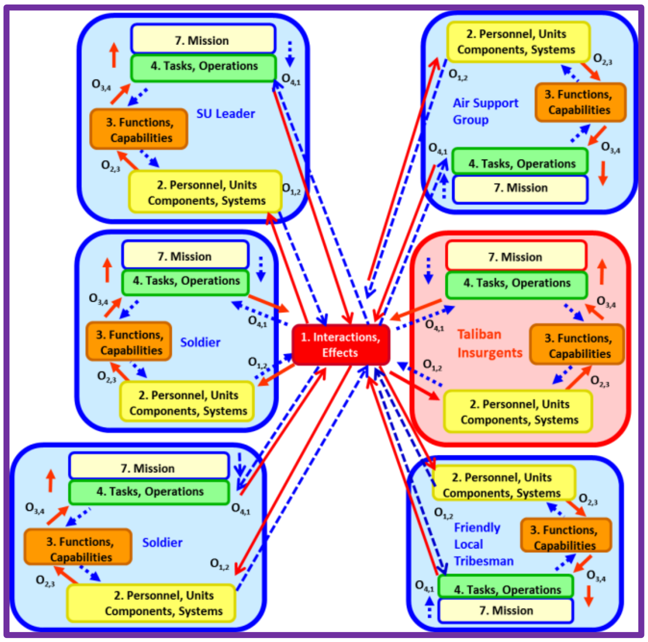

Figure 2. The MTMMF as A Generic Model for Showing Interactions among the Taliban Insurgents, Soldiers, Air Support Group, Friendly Local Tribesman, and SU Leader, In an Integrated View, On the Battlefield [Nyamekye 2011.]

Its objective is to provide a framework to help the SU leader, engineer, and comptroller specify a common understanding of military operations -- such as load planning and route selection [Nyamekye 2011] --, and information, and to provide quantitative mission assessment of alternative planning solutions. It provides a disciplined process to explicitly specify the mission (e.g., the Soldier's mission or SU mission), allocate means (course of action which each Soldier or the SU will take to pursue the mission), and assess mission accomplishment (the analysis of the course of action to determine if the Soldier or the SU has achieved mission success). Levels 5 through 7 characterize the Mission portion of the MMF, while Levels 1 through 4 are considered the Means portion of the framework. Level 6 which shows the Environment – Operating Environment – deserves attention with respect to uncertainty, from the Operating Environment. We will discuss it shortly. Again, the "Means", in the basic MMF, include all resources and actions which the Soldier or the SU will apply in pursuit of the Missions and the objectives. For example, the Mission tasks, such as gathering intelligence of the enemy's cover and concealment for terrain analysis, functions and capabilities (i.e. communication, movement over rough terrain, protection, sustainment) which each Soldier or the SU would need to successfully execute the Mission task(s), the resources (supplies i.e. food and water), equipment (i.e. vehicles, boots, protective vests and helmets), technology (i.e. GPS with batteries, radios, personal digital assistants (PDAs), etc.) needed to deliver the required functions and capabilities given the mission conditions and so on, are all considered part of the Means to achieve the ends associated with each Soldier or the SU's mission. Please note that SU leader must consider and incorporate Levels 7 to 1 into the decision making process -- for example load planning and route selection [Nyamekye 2011]. The "OWN FORCE" may represent each Soldier or SU as a single node in a Net-Centric Ecosystem [Nyamekye 2010] and the "OPPOSING FORCE" may represent the enemy (the Taliban insurgents). Figure 1 is specifically for a single threaded mission – only SU operations are involved.

Events in Afghanistan conclusively suggest that the SU cannot operate as a single thread. For example, in many recent missions in Afghanistan's remote areas, the SU has always requested external support – for example, air support operations -- to defeat the Taliban insurgents. Thus, we must treat the SU as part of a Multi-Threaded MMF Model [Nyamekye 2010], Figure 2, which is an extension of the single-threaded mission -- Deitz et al. basic MMF Model, Figure 1. The MTMMF represents the generic model of the interactions between the enemies, SU, logistics operations, etc. in an integrated systems-of-system (SoS), on the battlefield. The Multi-Threaded MMF Model can represent each Soldier, SU or the "support group" as a single node, and more importantly each friendly Soldier as a single node such as the friendly local tribesman in the Net-Centric Ecosystem [Nyamekye 2010]. Such an integrated view is critically important because it provides cognitive aid to the SU unit leader in understanding the sociocultural interactions among the participants and how such interactions help the SU leader to select the best plan to defeat the enemy on the battlefield. Also, the integrated view provides a much better picture of intentional relationships with the SU, and the support group, when analyzing the terrain -- for example, for load planning and route selection [Nyamekye 2011].

Through Level-1 (Interactions, Effects), the SU leader could share a COP with other Soldiers in the SU, and other combat support organizations, for creating a shared situation awareness of an insurgent's mission, such as creating and locating an improvised explosive device (IED) in the terrain (Operating Environment) to hurt the Soldiers, on the battlefield. The details of each MTMMF level follow.

Level-7 establishes the dismounted SU's Mission, e.g., Dislodge the Taliban insurgents from the rural and remote areas near the Kandahar city to prevent the Taliban insurgents from moving into the city. Level-6 describes the (Context, Environment) for the mission, e.g., human intelligence information in textual descriptive format – unstructured data format about the Taliban insurgents' intent, the terrain data, etc. Level-6 (Operating Environment) is where uncertainty occurs – e.g., insurgents intentionally using some deceptive measure such as actually creating a wedding-type celebration scenario where some other local tribesmen shoot into the air as celebrating some wedding but the actual insurgents are in some other location. We will shortly discuss how uncertainty affects the *choice or decision making* of the SU.

Level-5 identifies the (Index, Location & Time) for the mission, e.g., the geospatial data (from inter-visibility tools) describing the location and time for the mission. Level-4 establishes SU mission (Tasks, Operations), e.g., "Get the ISR sensor feeds for creating the shared situation awareness of the Taliban insurgent's intent". Level-4 also establishes the measure of performance/measure of effectiveness (MOP/MOE), for each mission task, e.g., throughput time for data transfer, overall mean time for each task, etc. Level-3 establishes the capabilities and functions (set of actions) that each Soldier or the SU would need to successfully perform the mission task. The SU may, for example, be given the mission task of conducting a tactical movement from a Combat Out Post to an isolated village in a critical valley. Factors such as the distance to be traveled, intervening terrain, threat of attack from insurgents, time available, and road conditions, will result in different sets of required capabilities and functions (i.e. aerial insertion versus vehicle or foot movement). Please note that the capabilities and functions (set of actions) are contained in the Operation Order, for each Soldier. The SU leader informally applies an abbreviated version of the Military Decision Making Process (MDMP) to develop an Operation Order which provides the task and purpose for each Soldier in the SU. The SU leader task organizes available personnel and equipment by *choosing* the best possible match of the capabilities and functions they deliver to the capabilities and functions required by each task. The written or verbal Operation Order is a product of this analysis. Level 2 also includes the C++ codes for the geospatial data or terrain data in the form of Services, Interface Definition Language (IDL) for exposing the Services to a middleware such as the Real-Time Innovations (RTI) Data Distribution Services (DDS). Please note that RTI DDS -- middleware -- permits the SU leader to send the Operation Order to each Soldier, and the support organizations, etc., through some intermittent network, in IW. Level-1 establishes the (Interactions, Effects) among the entities – between the Soldiers in SU, the support organizations, and between the SU, support group, and the Taliban insurgents. Level-1 represents execution of the *chosen plan* – e.g., load plan and route selection -- to fulfill the Level-7 Mission and *anti-selfishness principle*.

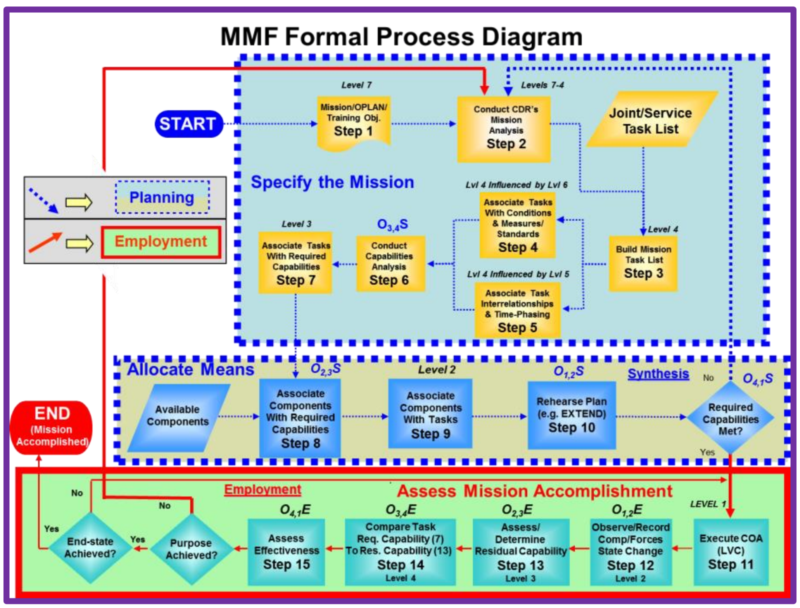

Figure 3. Diagram Showing the Detailed Relationships Between Level-5 (Index, Location & Time) and Level-6 (Context, Environment) On Level-4 (Tasks, Operations) and Level-3 (Functions, Capabilities) [Deitz et. al. May 2006.]

Consider Figure 3, which shows the detailed relationships between Level-6 (Context, Environment (Operating Environment)) and Level-4 (Tasks, Operations) and Level-3 (Functions, Capabilities). Please note that Figure 3 is an extension of Figure 1. For each Mission, Level-7, the SU leader must not only construct the Mission Task, Level-4, associated with the Mission, but also the SU leader must also establish the effect (influence, Step 4) of uncertainty from the Environment (Operating Environment), Level-6 – Associate Tasks With Conditions & Measures/Standards, on Mission Task, Level-4. This in turn requires the new *choice prediction and choice selection* of Level-3 (Functions, Capabilities) – Steps 6 and 7, associated with the Mission Task, Level-4. This is how we model the effect of uncertainty (from the operating environment) and complexity on *choice prediction and choice selection*, in RGT, as noted before.

Using Axiomatic Design, Design Navigation Method, and experimental design approach, we must also run experimental tests to validate that the *predicted choices and the selected choices*, indeed achieve the Mission Task, Level-4, which in turn achieves the overall Mission, Level-7.

AXIOMATIC DESIGN, DNM, AND EXPERIMENTAL DESIGN FOR VALIDATION OF PREDICTED CHOICES AND SELECTION OF PREDICTED CHOICES

Suh, from Massachusetts Institute of Technology (MIT) [Suh 1990], established two fundamental axioms that form the scientific basis of the axiomatic approach to design -- Axiomatic Design. They are:

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.

AXIOM 1 simply states that in designing any product or system, we must meet the goals (strategic or tactical requirements) of the system or product independently -- no coupling. For example, suppose the goals of designing an information visualization system are: 1) maximize the information benefits per unit cost and 2) minimize the total operational cost. According to AXIOM 1, the final design must satisfy both goals independently. Meeting the first goal should not affect the second goal. AXIOM 2 says that among the different designs that will meet both goals, the design that will require the least amount of information to describe it or will achieve the highest reliability of the product or system will be the best design. AXIOM 2 establishes the scientific foundation for an optimum design of a product, process or a system, e.g., methodologies and algorithms for *load planning and route selection*, software (e.g., applications and services for *load planning and route selection*), organization, and so on. We should note that classical optimization models, from operation research field, do not generally yield optimum results when more than one criterion for which the system must be optimized exists [Nakazawa 2001; Nyamekye 2009]. For example, when the goals of designing logistics system are both maximizing customer service and minimizing the distribution costs, classical optimization models do not achieve optimum results. Consequently, axiomatic approach is superior to the traditional optimization techniques when the design must meet more than one goal, concurrently [Nakazawa 2001; Nyamekye 2009]. In addition to AXIOMS 1 and 2, Suh has established corollaries, theorems, and constraints for design. For simplicity, we will omit the discussions of the corollaries, theorems and constraints. AXIOM 2 models uncertainty and complexity [Suh 1990; Suh 2001] associated with ***choice selection in decision making***. For example in load planning and route selection in remote areas (Context, Environment) where much uncertainty, such as the enemy hideouts in caves (complex terrains), we can use AXIOM 2 to select the optimum combination of load planning and route selection for the SU leader. Using the MTMMF paradigm, Nyamekye [Nyamekye 2011] has recently shown that AXIOM 2 of Axiomatic Design is an extremely powerful scientific model that can be used for *choice selection* of Level-3 (Functions, Capabilities) that would eventually lead to the *best selection of planning and execution models* for the SU leader.

EXPERIMENTAL TEST RUN NUMBER FOR A MISSION TASK (Level-4) FOR A GIVEN ROUTE	FUNCTIONS (Level-3) THAT MUST BE PERFORMED TO EXECUTE A MISSION TASK, AT THE FOLLOWING DESIGN PARAMETERS OR OPERATING VARIABLES, FOR EACH EXPERIMENTAL TEST RUN				EXPERIMENTAL OR SIMULATION RESULTS FOR FUNCTIONAL REQUIREMENTS (FRs) – MOPs/MOEs; NOTE: MOPs/MOEs ARE THE PARAMETERS THAT EVALUATE THE PERFORMANCE OF THE STATISTICAL OUTCOMES – CAPABILITIES (Level-3) - - FOR PERFORMING THE FUNCTIONS (Level-3).					
	PERFORM THE FUNCTIONS ASSOCIATED WITH MOVING ALONG A ROUTE TO EXECUTE A MISSION TASK				ENERGY COST OF MOVEMENT (ECM)	COGNITIVE DEGRADATION (CD)	PHYSICAL DEGRADATION (PD)	THERMAL BURDEN (TB)	HEAT STRAIN (HS)	ARRIVAL TIME (AT)
	OPERATING FACTORS OR DESIGN PARAMETERS (DPs)									
	OACOK	LOAD	PERSONNEL KEY PARAMETERS (PERSTAT)	INTERVISIBILITY TOOLS						
1										
2										
3										
4										
5										
6										
7										
8										
9										

Table 1. Generic Experimental Design Model using Mission Command-Based Test and Evaluation (MCBT&E) Concepts for Load Planning and Route Selection [Nyamekye 2011.]

EXPERIMENTAL TEST RUN NUMBER FOR A MISSION TASK (Level-4) FOR A GIVEN ROUTE	FUNCTIONS (Level-3) THAT MUST BE PERFORMED TO EXECUTE A MISSION TASK, AT THE FOLLOWING DESIGN PARAMETERS OR OPERATING VARIABLES, FOR EACH EXPERIMENTAL TEST RUN.					EXPERIMENTAL OR SIMULATION RESULTS FOR FUNCTIONAL REQUIREMENTS (FRs) – MOPs/MOEs; NOTE: MOPs/MOEs ARE THE PARAMETERS THAT EVALUATE THE PERFORMANCE OF THE STATISTICAL OUTCOMES -- CAPABILITIES (Level-3) -- FOR PERFORMING THE FUNCTIONS (Level-3).		
	PERFORM THE FUNCTIONS ASSOCIATED WITH MOVING ALONG A ROUTE TO EXECUTE A MISSION TASK					ENERGY COST OF MOVEMENT (ECM)	COGNITIVE DEGRADATION (CD)	PHYSICAL DEGRADATION (PD)
	OPERATING FACTORS OR DESIGN PARAMETERS (DPs)							
	OSB. & FIELDS OF FIRE (OFF)	AVENUES OF APPROACH (AA)	COVER AND CONCEALMENT (CC)	OBSTACLES (O)	KEY OR DECISIVE TERRAIN (KODT)			
1	OFF1	AA1	CC1	O1	KODT1	ECM1	CD1	PD1
2	OFF1	AA2	CC2	O2	KODT2	ECM2	CD2	PD2
3	OFF1	AA3	CC3	O3	KODT3	ECM3	CD3	PD3
4	OFF2	AA1	CC1	O1	KODT1	ECM1	CD1	PD1
5	OFF2	AA2	CC2	O2	KODT2	ECM2	CD2	PD2
6	OFF2	AA3	CC3	O3	KODT3	ECM3	CD3	PD3
7	OFF3	AA1	CC1	O1	KODT1	ECM1	CD1	PD1
8	OFF3	AA2	CC2	O2	KODT2	ECM2	CD2	PD2
9	OFF3	AA3	CC3	O3	KODT3	ECM3	CD3	PD3

Table 2. Partial Experimental Design Model (From Table 1), Showing only the Details for Observation and Fields of Fire, Avenues of Approach, Cover and Concealment, Obstacles, and Key or Decisive Terrain (OACOK) factors, and Energy Cost of Movement (ECM); Cognitive Degradation (CD); and Physical Degradation (PD) [Nyamekye 2011.]

We will borrow from Nyamekye's recent publication [Nyamekye 2011] on Mission Command-Based Test and Evaluation (MCBT&E) model for load planning and route selection, to discuss the generic experimental design approach which can be adapted for experimental design to evaluate the *choice selection* for RGT paradigm. Tables 1 and 2 show the detailed experimental design tables.

Table 1 is based on Design Navigation Method (DNM), an extension of Axiomatic Design [Nakazawa 2001; Nyamekye 2009]. In Table 1, the first column represents the SU or the Soldier's **mission task** for any route. The second column represents the functions (*the set of selected choice of actions*) that the Soldier will perform to execute the **mission task**, for any route. Along that route the SU unit leader must perform the detailed analysis of the design parameters (DPs) -- OACOK factors, load, Personal Status (PERSTAT), intervisibility tools, etc., which will vary as the Soldier moves along the route. Please note that OACOK stands for Observation and Fields of Fire, Avenues of Approach, Cover and Concealment, Obstacles, and Key or Decisive Terrain [Slideshare 2011]. These parameters will also influence the SU's route selection and load planning. The last column represents the primary performance measures – energy cost of movement, cognitive degradation, physical degradation, thermal burden, heat strain, and arrival time. Please note that when certain mission tasks – e.g., "Get the ISR sensor feeds for creating the shared situation awareness of the Taliban insurgent's intent" – require different DPs, we can easily incorporate the new DPs into the model. Table 2 represents a partial subset of the detailed experimental design model for the OACOK factors. The cells in Table 2 represents the levels for each factor, e.g., OFF1 represents a low level "observation and fields of fire", designated as minus sign (-); OFF2 represents a medium level "observation and fields of fire", designated as plus sign (+); and OFF3 represents a high level "observation and fields of fire", designated as plus sign (+) [Nyamekye 2011]. For lack of space, we have omitted the details for other DPs and FRs, respectively.

Nakazawa [Nakazawa 2001] has nicely discussed the algorithm for evaluating the total minimum information content (AXIOM 2) for several functional requirements, FRs (MOPs/MOEs), for example, energy cost of movement (ECM), cognitive degradation (CD), etc. He calls the overall design concept, Design Navigation Method. For convenience, we will use the symbols from his work. The algorithmic steps are as follows. In Figure 4, the A1, A2, Ap represent the different levels of a design parameter, DP, e.g., "observation and fields of fire," and the FRs represent the functional requirements, e.g., ECM. The design parameters (DPs) correspond to the variables or parameters that we can vary to achieve FRs. Consider the ***functions (Level-3) that are associated in moving along any route which is chosen as the first route***, to execute the ***mission task(s)***. First we vary the DPs to take on the values, A1,...A2,...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 data points gathered, the mean **m**, and **σ**, the standard deviation (square root of unbiased variance), are obtained. The two points, representing **m** + **kσ**, are then plotted above A1, as we can see in Figure 4. 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 "energy cost of movement (ECM)". We then repeat the same method for the upper and lower limits for the rest of the parameter values, A1,…Ap. 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, **Ed** such as the range of acceptable **energy cost** established by the central commander), for the upper value and the lower value, on the same graph, as we can see in Figure 4.

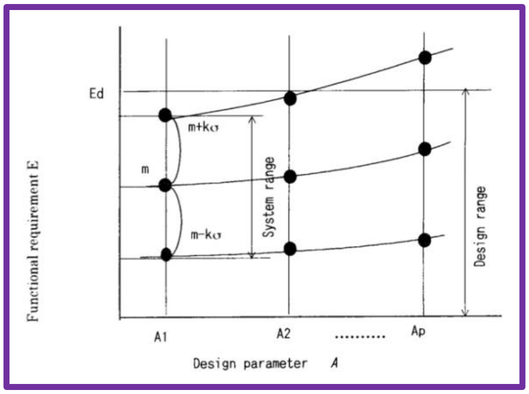

Figure 4. System Range of Design Parameter A for Functional Requirement [Nakazawa 2001; Nyamekye 2009.]

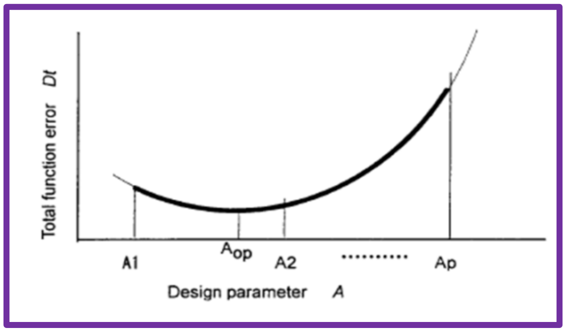

Figure 5. Total Information Content (Function Error Curve) [Nakazawa 2001; Nyamekye 2009.]

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 2009], 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 "cognitive degradation" 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 5 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, between 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 and complexities on the battlefield. For the **same mission task(s),** we repeat the same procedure for the **other routes** and *select the* best *combination of load and route* with the total minimum information content, associated with the *chosen predicted choice(s)* – e.g., aerial insertion, vehicle or foot movement. 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 – such as in Tables 1 and 2. For simplicity, we have omitted the details.

REFLEXIVE GAME THEORY (RGT) FOR THE LIBYAN CONFLICT, AS AN EXAMPLE OF COMPLEX ENDEAVORS

The overall Mission, Level-7, of the Libyan conflict, established by the United Nations Security Council (UNSC) Resolution (1973, was: "create and enforce a no-fly zone to protect the civilians". The Rebel Forces (RF) tactical goals – Level-4 Mission Tasks were: "liberate Libya and form a democratic government". The tactical goals of United States Forces (USF), the French Forces (FR), and the British Forces (BR), were similar to the tactical goals of the Rebel Forces except that each entity publicly declared its own tactical goal -- Level-4 Mission Task, to be: "the Libyans must choose their own democratic government". They (USF, FR, and BR) needed to publicly declare such as a Level-4 Mission Task to avoid violating the United Nations Security Council Resolution 1973. Gaddafi Forces (GF), tactical goal -- Level-4 Mission Task, was – "keep the current government". Quite typical in *complex endeavors*, the questions that constantly cropped up during the Libyan conflict were, 1. What is the overall Mission of the USF? 2. Who is in charge of the Mission – UNSC, USF, FR, or BR? 3. What is the end state of the USF? In complex endeavors, no single entity is in charge of the overall Level-7 Mission. In fact, a similar situation arises in natural disaster relief efforts when Level-7 Mission is unclear, the Level-4 Mission Task(s) not properly defined by the entities participating in the natural disaster relief efforts, and more importantly the lack of a clear entity to lead Level-7 Mission.

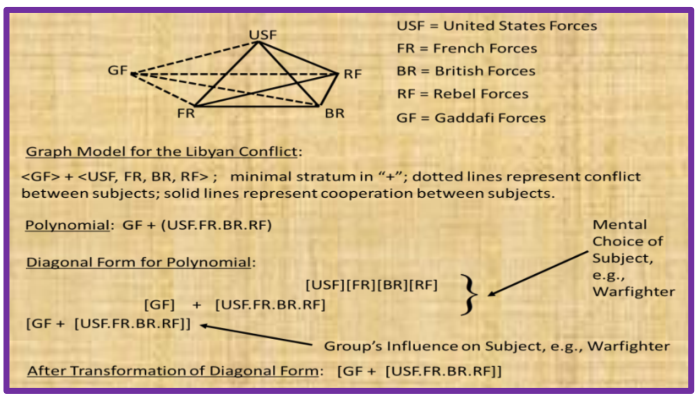

Figure 6. Reflexive Game Theory Algorithm for Representation of a Group.

Figures 6 to Figure 10 illustrate not only the detailed steps in using RGT for *choice prediction and choice selection* of Level-3, Functions, Capabilities for the Libyan conflict, but also they establish the generic algorithm for *choice prediction and choice selection* of Level-3, Functions, Capabilities, in MTMMF for *complex endeavors*. Please note that because of lack of information on operating variables or design parameters (DPs) associated with *each set of predicted Functions*, *(or predicted Capabilities*), and more importantly lack of information for uncertainty that occurred during the conflict, we could not conduct experimental tests, similar to Tables 1 & 2, for the Libyan conflict. Despite such lack of information, *the predicted set of Functions (Capabilities)*, Level-3, and the *predicted selection of set "realizable" Functions (Capabilities),* Level-3, were in remarkably agreement with the final results of the conflict. The RGT begins with the definition of the subjects – constituting the *complex endeavors* --, which in this example are, namely, Figure 6: United States Forces (USF), French Forces (FR), British Forces (BR), Rebel Forces (RF) and Gaddafi Forces (GF). The next step is the construction of the graph model, Figure 6, which represents the relationships between the subjects. For example the dotted line represents conflict, and solid line represents cooperation. Please notice that except for Gaddafi Forces (GF) that are in conflict with the other forces, the rest of the forces are in cooperation with each other. For details about constructing the graph model in RGT, please see the work of Lefebvre [Lefebvre 2010]. From the graph model, Figure 6, we then construct the polynomial, Figure 6, which represents the analytical notation of the graph model, where the "+", represents the Boolean operation for addition, and "**.**", represents the Boolean operation for multiplication [Lefebvre 2010]. Again, for details about the polynomial in RGT, please see the work of Lefebvre [Lefebvre 2010].

The next step is to convert the polynomial into diagonal form, Figure 6. The first part of the diagonal form represents the group's influence on the subject, in making a choice or decision. The rest of the diagonal form represents the mental choice (from the cognitive system) of the subject. We can think of the diagonal form as an exponential function, where the base of the exponential function is the same as the polynomial and the exponent is the mental choice of the subject, in decision making. Again, for details about the diagonal form in RGT, please see the work of Lefebvre [Lefebvre 2010].

Using the Boolean algebra, we can then transform the diagonal form into a final analytical form. For details about this transformation, please see the work of Lefebvre [Lefebvre 2010]. Using the Boolean algebra, we then simplify the final analytical form to obtain the generic choice equation for each subject, Equation 1, (same equation in Figure 7), and check if the choice equation has a solution, Equation 2, (same equation in Figure 7). Please see Page 8, for Equations 1 and 2.

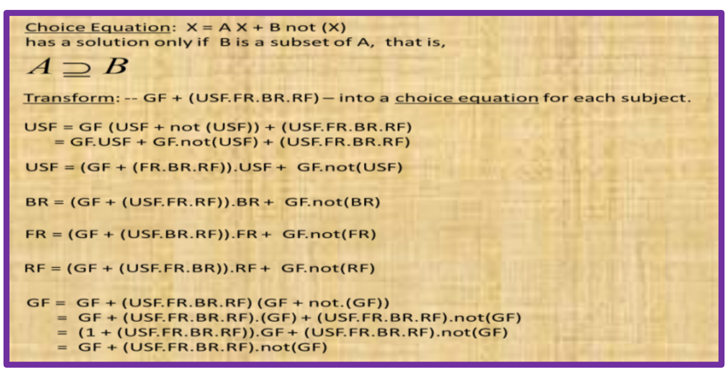

Figure 7. Reflexive Game Theory Algorithm for Representation of a Group -- Continued.

If no solution exists, it means the subject cannot make a *choice or decision* [Lefebvre 2010].

Using the generic choice equation, we can find specific choice equation for each subject, namely: USF, BR, FR, RF, GF. Again, for details of each subject's choice equation, please see the work of Lefebvre [Lefebvre 2010]. We then define the group(s) set of actions, construct the universal set of actions for the group(s), construct the set of all subsets of universal set M, which includes the empty set, and create the matrix of influence table. Figure 8 shows the details. Please note that because each subject's *intention* – called *self-influence* --, for choosing one or another of the alternatives (set of actions) [Lefebvre 2010], is unknown for the Libyan conflict, we modeled the Libyan conflict as intentional subjects.

SUBSETS OF UNARY COURSES OF ACTION -- FUNCTIONS , Capabilities -- LEVEL-3 IN MTMMF

Let α = Degrade the air defense systems of Kaddafi's forces, supplemented with airstrikes to destroy Kaddafi Army's tanks.

Let β = Deploy ground troops.

Let γ = Arm the rebels .

Let μ = Gaddafi leaves power.

Let τ = Gaddafi stays in power.

SUBSETS OF ALL COURSES OF ACTION -- FUNCTIONS, Capabilities -- LEVEL-3 IN MTMMF

1 = {α, β, γ, μ, τ}; {α, β}; {α, γ}; {α, μ}; {α, τ}; {β, γ}; {β, μ}; {β, τ }; {γ, μ}; {γ, τ}; {μ, τ}; {α, β, γ}; {α, β, μ}; {α, β, τ}; {α, γ, μ}; {α, γ, τ}; {α, μ, τ}; {β, γ, μ}; {β, γ, τ}; {β, μ, τ }; {γ, μ, τ }; {α, β, γ, μ}; {α, β, γ, τ }; {α, β, μ, τ}; {α, γ, μ, τ }; {β, γ, μ, τ }; {α}; {β}; {γ}; {μ}; {τ}; {} = 0. These sets, which include the empty set, constitute M.

Matrix of Influences For Libyan Conflict -- Intentional Subjects

	USF	BR	FR	RF	GF
USF	**USF**	USF = {α, μ}	USF = {α, μ}	USF = {γ}	USF = {μ}
BR	BR = {α, β, γ, μ}	**BR**	BR = {α, β, γ,μ}	BR = {γ}	BR = {μ}
FR	FR = {α, β, γ, μ}	FR = {α, β, γ, μ}	**FR**	FR = {γ}	FR = {μ}
RF	RF = {α, β, γ, μ}	RF = {α, β, γ, μ}	RF = {α, β, γ, μ}	**RF**	RF = {μ}
GF	GF = {τ}	GF = {τ}	GF = {τ}	GF = {τ}	**GF**

Let {δ} = {α, β, γ, μ}; {η} = {α, μ}

Figure 8. Reflexive Game Theory Algorithm for Representation of a Group -- Continued.

Consider the matrix of influence, Figure 8. The diagonal entries (in bold face), represent the subject's *intentions*. Each row represents the influence each subject exerts on the other subject and the subject's own self. For example during the Libyan war, the British Forces (BR) influenced the United States Forces (USF) -- $\{\alpha, \beta, \gamma, \mu\}$ – to do the following: degrade the air defense systems of Kaddafi's forces, supplemented with airstrikes to destroy Kaddafi Army's tanks $\{\alpha\}$, deploy ground troops $\{\beta\}$, arm the rebels $\{\gamma\}$, Gaddafi leaves power $\{\mu\}$. The British Forces (BR) also exerted influence on its own forces – diagonal element (BR). In addition, the British Forces (BR) influenced the French Forces (FR) – $\{\alpha, \beta, \gamma, \mu\}$ – to do the following: degrade the air defense systems of Kaddafi's forces, supplemented with airstrikes to destroy Kaddafi Army's tanks $\{\alpha\}$, deploy ground troops $\{\beta\}$, arm the rebels $\{\gamma\}$, Gaddafi leaves power $\{\mu\}$. Furthermore, the British Forces (BR) influenced the Rebel Forces {RF} to arm themselves $\{\gamma\}$, and influenced Gaddafi to leave power $\{\mu\}$. Each column represents the influence that the other subjects exert on the subject.

A variety of ways exists to represent how the participants can exert influences among each other. One example is through direct "email exchanges" among the participants. Another example is through telegraph communication, such as "telegrams", through diplomatic channels among the participants (senior leaders). For example during the Libyan war, Gadhafi sent a letter to President Barack Obama, to <u>influence</u>, $\{\tau\}$, Figure 8, President Obama <u>to halt the war</u> [Huffington Post 2011]. We should emphasize that the author, in collaboration with Lefebvre [Lefebvre 2010], is creating a software package for deployment on <u>tablets,</u> to implement the model. Using the standard Application Programming Interfaces (APIs) of Rest Architectural Style [Fielding 2000], the author, in collaboration with Lefebvre [Lefebvre 2010], will create the <u>user interfaces</u> and deploy them on <u>tablets,</u> to construct the universal set of actions and for sharing information about the influences. Figures 9 and 10 show each subject's *predicted choices* and the *appropriate selection of choices* for each subject. For simplicity, we have left out discussing the detailed results of Equation 2.

USF = (GF + (FR.BR.RF)).USF + GF.not(USF)

USF = ({τ}+ ({δ}.{δ}.{δ}).USF + {τ}.not(USF) = ({τ} + {δ})USF + {τ}.not(USF) = {τ,δ} USF + {τ}.not(USF);
B= {τ}; A = {τ,δ}; USF makes a choice at least between {τ} and {τ,δ}. **USF chooses {α, μ}.**

BR = (GF + (USF.FR.RF)).BR + GF.not(BR)

BR = ({τ} + ({η}.{δ}.{δ})).BR + {τ}.not(BR) = ({τ} + {η})BR + {τ}.not(BR) = ({τ,η}BR + {τ}.not(BR); B= {τ}; A = {τ,η}; BR makes a choice at least between {τ} and {τ,η}. **BR chooses {α, μ}.**

FR = (GF + (USF.BR.RF)).FR + GF.not(FR)

FR = ({τ} + ({η}.{δ}.{δ})).FR + {τ}.not(FR) = ({τ} + {η})FR + {τ} .not(FR) ={τ,η}}FR + {τ}.not(FR);
B= {τ}; A = {τ,η}; FR makes a choice at least between {τ} and {τ,η}. **FR chooses {α, μ}.**

RF = (GF + (USF.FR.BR)).RF + GF.not(RF)

RF = ({τ} + ({γ}.{γ}.{γ})).RF + {τ}.not(RF) = ({τ} + {γ})RF + {τ}.not(RF) = {τ,γ}RF + {τ}.not(RF);
B= {τ}; A = {τ,γ}; RF makes a choice at least between {τ} and {τ,γ}. **RF chooses {γ}.**

GF = GF + (USF.FR.BR.RF).not(GF)

GF = GF + ({μ}.{μ}.{μ}.{μ}).not(GF) = GF + {μ}.not(GF)
= (1)GF + {μ}.not(GF);
B= {μ}; A = 1; GF makes a choice at least between {μ} and 1. **GF chooses {τ}**

Figure 9. Reflexive Game Theory Algorithm for Representation of a Group – Continued.

SUBSETS OF UNARY COURSES OF ACTION -- FUNCTIONS , Capabilities -- LEVEL-3 IN MTMMF

Let α = Degrade the air defense systems of Kaddafi's forces, supplemented with airstrikes to destroy Kaddafi Army's tanks.

Let β = Deploy ground troops.

Let γ = Arm the rebels .

Let μ = Gaddafi leaves power.

Let τ = Gaddafi stays in power.

SUBSETS OF ALL COURSES OF ACTION -- FUNCTIONS, Capabilities -- LEVEL-3 IN MTMMF

1 = {α, β, γ, μ, τ }; {α, β}; {α, γ}; {α, μ}; {α, τ}; {β, γ}; {β, μ}; {β, τ }; {γ, μ}; {γ, τ}; {μ, τ}; {α, β, γ}; {α, β, μ}; {α, β, τ}; {α, γ, μ}; {α, γ, τ}; {α, μ, τ}; {β, γ, μ}; {β, γ, τ}; {β, μ, τ }; {γ, μ, τ }; {α, β, γ, μ}; {α, β, γ, τ }; {α, β, μ, τ}; {α, γ, μ, τ }; {β, γ, μ, τ }; {α}; {β}; {γ}; {μ}; {τ}; {} = 0. These subsets, which include the empty set, constitute all the available subsets of courses of action for each subject -- Means in MTMMF. Please note that the universal set of actions is 1 = {α, β, γ, μ, τ }.

REALIZATION OF CHOICES

USF: {α, μ}; {α}; {μ} -- USF can realize any of the three subsets of action.

BR: {α, μ}; {α}; {μ} – BR can realize any of the three subsets of action.

FR: {α, μ}; {α}; {μ} – FR can realize any of the three subsets of action.

RF: {γ} – RF can realize one subset of action.

GF: {τ} – GF can realize one subset of action.

Figure 10. Reflexive Game Theory Algorithm for Representation of a Group – Final.

Of particular importance is Figure 10, which shows the realization of choices. The USF had three alternatives -- $\{\alpha, \mu\}$; $\{\alpha\}$; $\{\mu\}$ --, but realized only one choice -- degrade the air defense systems of Kaddafi's forces, supplemented with airstrikes to destroy Kaddafi Army's tanks $\{\alpha\}$. Similar to the USF, both the BR and FR had three alternatives. Each realized the same choice as the USF. The RF had only one alternative -- $\{\gamma\}$ -- and realized that choice – arm themselves. The GF had only one alternative – $\{\tau\}$ and realized that choice – stayed in power until they were dismantled and Kaddafi was finally captured and killed. As noted before, the predicted choices were in remarkable agreement with the end results of the Libyan conflict.

Throughout the conflict the *anti-selfishness principle* was fulfilled by each of the coalition partners – USF, FR, BR, -- and the Rebel Forces (RF). For example, when the RF were achieving their Level-4 Mission Tasks -- "liberate Libya and form a democratic government", *they never caused any harm to the group they were a member of*. The group included -- USF, FR, BR, and RF. Similarly, each coalition partner also fulfilled the *anti-selfishness principle*. Gaddafi Forces (GF), collectively as a different group, also fulfilled the *anti-selfishness principle*. That is, within the Gaddafi Forces, the members never caused harm to each other while achieving their own Level-4 Mission Task – "keep the current government".

Again, we should emphasize that when much uncertainty and complexity exist in Level-6 Context, Environment, which will influence Level-4 Tasks, Operations, and Level-3 Functions, Capabilities, we need to use Axiomatic Design, Design Navigation Method, and experimental design approach, as noted before, to evaluate if the predicted choices and the selected alternative(s), fulfill the Level-7 – Mission and *anti-selfishness principle*.

CONCLUSIONS

Using the Reflexive Game Theory (RGT), this paper has established a new and emerging powerful scientific paradigm – for *choice or decision making*, for the Warfighter or Small Unit (SU) leader, in *complex endeavors*. The paper recognizes the two deficiencies in the classical game theory, namely: irrational risk a player is inclined to make, and the lack of cognitive model in the classical decision making function. Drawing on the recent report of the National Research Council study on improving the decision making ability of the SU leader, the paper has discussed the scientific approach for using RGT for *choice or decision making,* which includes the mental model of the Warfighter in *complex endeavors*. In particular, the paper has addressed the *anti-selfishness principle* which must augment the descriptive model and prescriptive model for *choice or decision making*. The paper has also discussed RGT as a unique model for creating purposeful agent-based system – new and emerging breed of intelligent systems, with cognitive capabilities – to support the Warfighter or the SU leader in IW. In fact, the concepts in the paper could be adapted to generate new frontier of scientific research programs in *cognitive neuroscience,* as echoed in the recent report of the National Research Council study. Using AXIOM 2 of Axiomatic Design and Design Navigation Method, the paper has discussed experimental design to validate the predicted choices and the selection of "realizable" alternatives when much uncertainty and complexity, in the operating environment, can influence the predicted choices and the selection of "realizable" alternatives. The paper has also emphasized the importance of using Multi-Threaded Missions and Means Framework (MTMMF) as the basis for defining the set of actions or Functions, Capabilities – Level-3 in MTMMF -- *for choice prediction and choice selection*. Using the Libyan conflict as a case study, the RGT has demonstrated that it is a very powerful scientific paradigm for *choice or decision making*, for the Warfighter, in *complex endeavors*. In fact, the results from the case study were in remarkable agreement with the end results of the Libyan conflict.

Consider adapting this model for the SU leader, as follows. Suppose we have already created and deployed a software package on a tablet for the SU leader. Suppose through experimentation, the SU leader has the following data: 1) Overall Mission, Level-7; 2) Google Maps depicting the enemy's Environment, Level-6 and Location, Level-5; 3) The associated Operations, Level-4, and the Functions (set of all actions), Level-3; and 4) The relationships among the participants and the influences each participant exerts on each other. The SU leader can input such data into the software package which will automatically generate Figure 2 (MTMMF diagram), the graph of relations, Figure 6, among the participants, and create the universal set of actions, $1=\{\alpha,\beta,\gamma,\mu,\tau\}$, and the subsets of all courses of action – Functions, Level-3, Figure 8, the matrix table of influences, Figure 8, and more importantly predict appropriate selection and realization of choices, Figure 10, and the associated Personnel, Units Components, Systems, Level-2 which the SU leader can deploy to attack -- Interactions, Effects, Level-1 -- the enemy.

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AUTHOR BIOGRAPHY

DR. KOFI NYAMEKYE is the president and chief executive officer of Integrated Activity-Based Simulation Research, Inc. 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 (FCS). He has published extensively on scientific design, multi-agent modeling, and simulation of integrated and adaptive C4ISR SoS. He holds a Doctor of Philosophy degree in industrial engineering from Pennsylvania State University, a Master of Science degree in mechanical engineering from Pennsylvania State University, and a Bachelor of Science degree in mechanical engineering from the University of Wisconsin-Madison. E-mail: kofinsoyameye@earthlink.net.