18th ICCRTS

"C2 IN UNDERDEVELOPED, DEGRADED AND DENIED OPERATIONAL ENVIRONMENTS"

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

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OVERVIEW OF PRESENTATION

- Cite direct excerpts from NRC's recent report on "*Improving the Decision Making Abilities of Small Unit Leaders"*.
- Discuss implication of NRC's excerpts on Warfighter, continuously shifting his or her cognitive system between combat operations and complex civil service operations.
- Discuss complex endeavors, and how it complicates the Warfighter's decision making.
- Emphasize that 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.
- Provide overview of Reflexive Game Theory, as an example of emerging scientific paradigm for decision making:
  - Includes mental model
  - Unique theory for creating a purposeful agent, purposeful individual or system
- Discuss mathematical model of RGT for *choice or decision* .
- Borrow from author's previous work to discuss Missions and Means Framework and Multi-Threaded Missions and Means Framework as the technical basis for defining the functions for choice prediction and choice selection.
- Discuss the effect of uncertainty and complexity on the choice model and choice selection. Draw on Axiomatic Design for constructing experimental design to address effect of uncertainty and complexity on decision making.
- Use the Libyan conflict as a case study.
- Draw conclusions.

Excerpt from National Research Council's Report [(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.*"

Excerpt from National Research Council's Report [(NRC) July 2012]

*“**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.”*

Excerpt from National Research Council's Report [(NRC) July 2012]

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]"

Implication Of NRC’s Excerpts On Warfighter, Continuously Shifting His Or Her Cognitive System Between Combat Operations And Complex Civil Service Operations

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 the 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.

Complex Endeavors[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.*

How Complex Endeavors Complicate The Warfighter's Decision Making

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.

The Libyan conflict was an example of complex endeavors. We will discuss this issue later.

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.

Overview of Reflexive Game Theory, As An Example Of Emerging Scientific Paradigm For Decision Making

From the viewpoint of classical game theory, decision making involves two types of theories, namely: <u>descriptive</u> and <u>prescriptive</u>. The <u>descriptive theory</u> is about <u>choice prediction</u> of a player [Lefebvre 2010], and the <u>prescriptive theory</u> 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. <u>More importantly, the classical game theory does not account for the cognitive system of the subject – e.g. the Warfighter -- in *decision making*</u>. The Reflexive Game Theory (RGT) addresses such deficiencies in *choice or decision making*.

Goal of Reflexive Game Theory (RGT)

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]. 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. The concept of *reflexive control* is very intriguing, 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.

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.

Implication Of *Anti-selfishness Principle* in Decision Making

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.

Purposeful Individual Or System [Ackoff et al. 2006; Lefebvre 2010] --The Basis For Purposeful Agent

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]. <u>More importantly, the environment of the individual or system cannot choose the goals for the purposeful individual or system</u>! 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.) <u>Only humans or people are purposeful individuals or systems</u>!

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!

Definition of Purposeful Agent

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].

<u>This is the fundamental difference between the traditional agent and the purposeful agent</u>. In fact North and Macal [North and Macal 2007, Page 102] clearly articulate the *<u>traditional agent</u>* as follows: "*The fundamental features that make something a candidate to be modeled as a <u>traditional agent</u> are the capabilities of the component to make independent decisions, some type of <u>goal</u> to focus the decisions, and the ability of other components to tag or individually identify the component.*" *Unlike the <u>purposeful agent</u> that sets its own goals, the <u>traditional agent</u> must use the goal set by some individual or the user of the system being modeled*.

Importance of Differentiating Between Traditional Agent and Purposeful Agent

This issue of differentiating between the traditional agent and purposeful agent is very 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.

Reflexive Game Theory, a Unique Scientific Theory for Creating Purposeful Agent

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*

In RGT we assume that a subject can perform actions , represented as follows:

$$\alpha_1, \alpha_2, \ldots, \alpha_S, S \geq 1$$

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 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 = { α_1, α_2 } and empty set as 0 = {}. Using the

Boolean algebra, we can represent all the possible alternatives (set of actions) as:
1 = { α_1, α_2 }, { α_1 }, { α_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 subjects of the universal set, -- 4 in the above case --, but also the set *M* as previously noted, includes not only the set of all subjects of the universal set, -- 4 in the above case --, but also the set includes the Boolean operations "+", "**.**", "***negation***", and the relation "***greater or equal***".

The choice of { α_1 } means that the subject can perform only action α_1, and the choice of { α_2 } means that he or she can perform only action α_2. Consider the alternative { α_1, α_2 }. Since the subject cannot perform actions α_1 (turn left) and α_2 (turn right) at the same time, alternative { α_1, α_2 } is not <u>realizable</u>. However, the subject can <u>realize</u> either subset { α_1 } or subset { α_2 } after he or she <u>chooses</u> alternative { α_1, α_2 }.

The subject does nothing if he or she chooses the empty set 0 = {}.

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

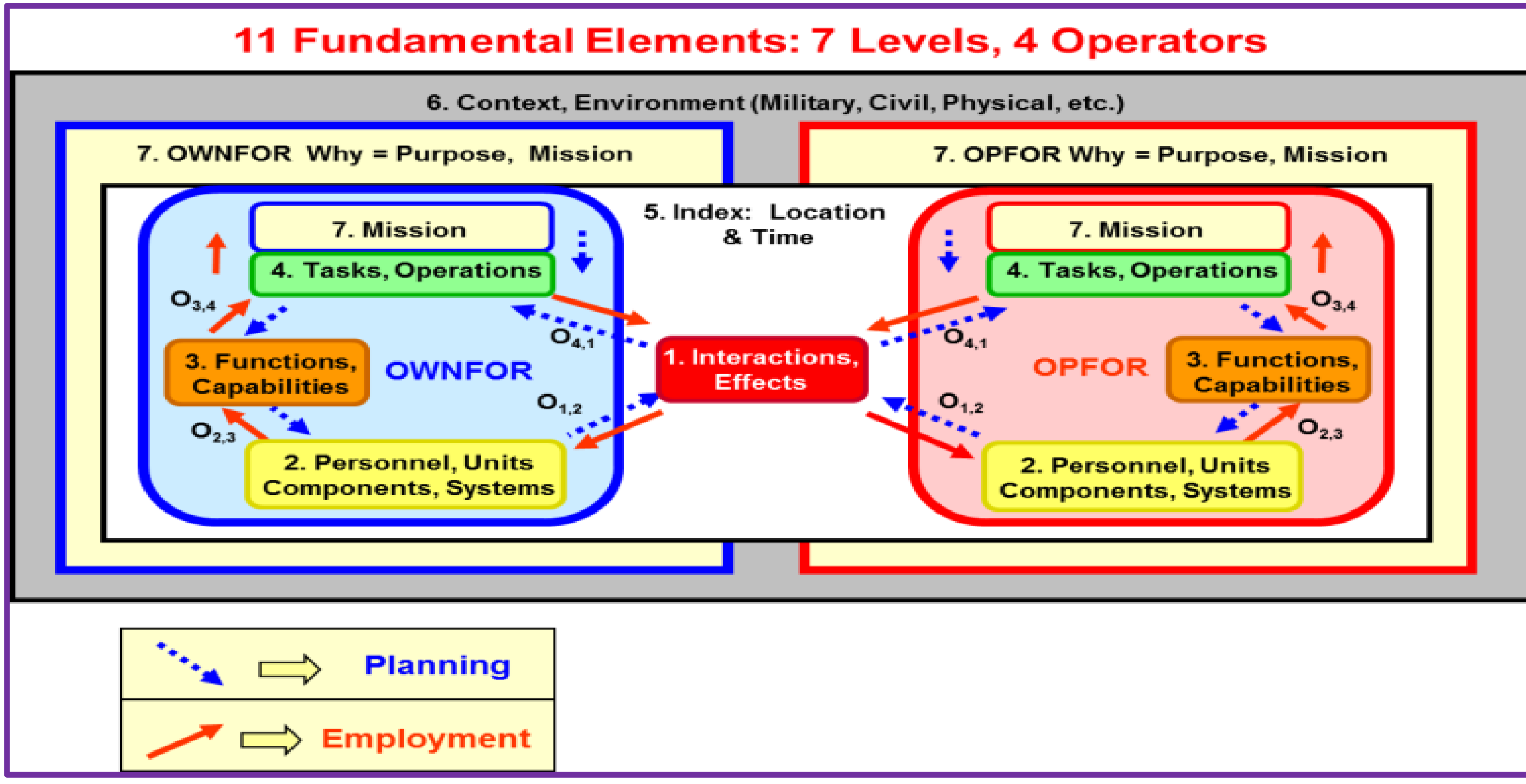
$$X = AX + B\ \mathrm{not}(X). \qquad \text{Equation 1}$$

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.

$$A \supseteq B \qquad \text{Equation 2}$$

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).

MISSIONS AND MEANS FRAMEWORK (MMF) and the Multi-Threaded Missions and Means Framework (MTMMF)



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

MISSIONS AND MEANS FRAMEWORK (MMF) and the Multi-Threaded Missions and Means Framework (MTMMF)

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

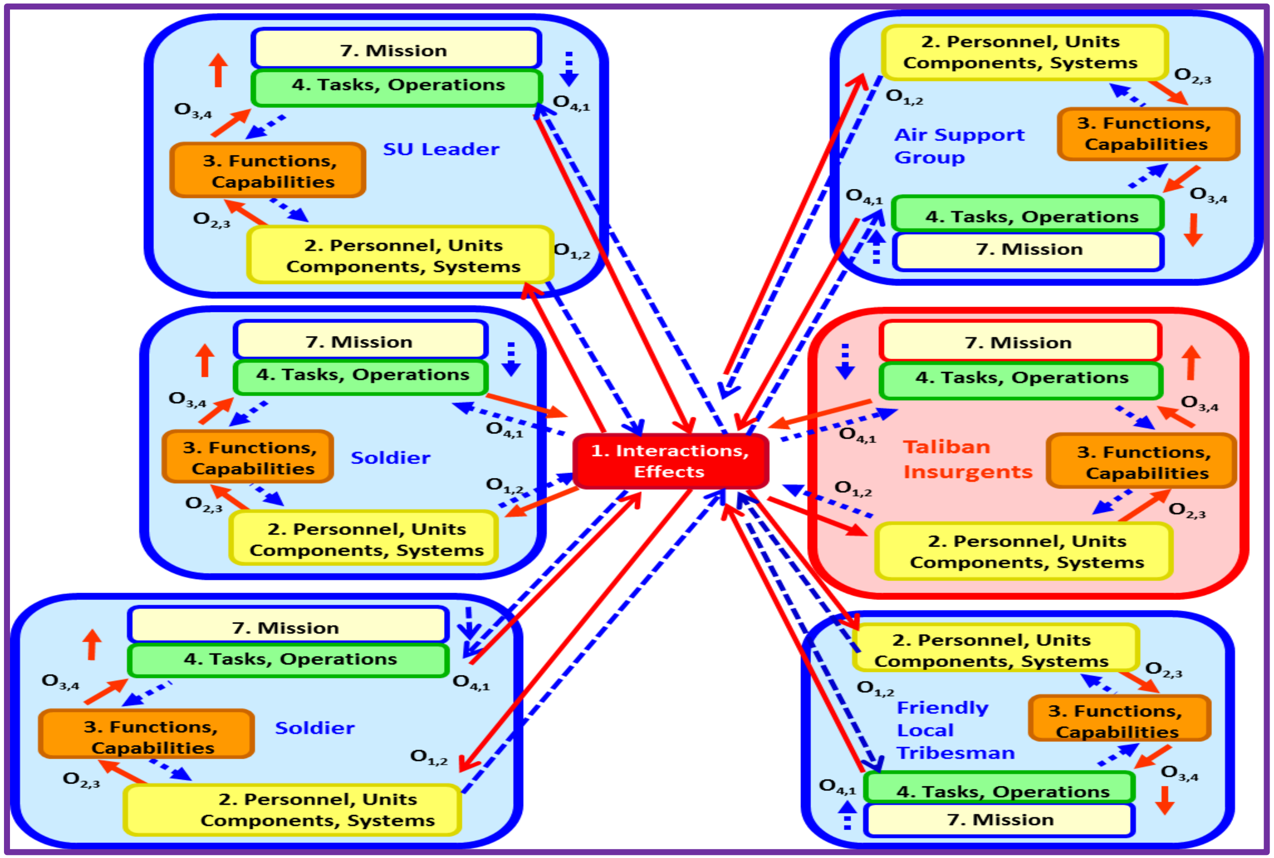
MISSIONS AND MEANS FRAMEWORK (MMF) and the Multi-Threaded Missions and Means Framework (MTMMF)

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). Deitz et. al. basic MMF model [Deitz et. al. May 2006] is specifically for a single threaded mission – e.g., only small unit (SU operations may be involved. In the basic MMF model, 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).

MISSIONS AND MEANS FRAMEWORK (MMF) and the Multi-Threaded Missions and Means Framework (MTMMF)

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], which is an extension of the single-threaded mission -- Deitz et al. basic MMF Model. 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 make better decisions 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, load planning and route selection [Nyamekye 2011].

MISSIONS AND MEANS FRAMEWORK (MMF) and the Multi-Threaded Missions and Means Framework (MTMMF)



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.]

MISSIONS AND MEANS FRAMEWORK (MMF) and the Multi-Threaded Missions and Means Framework (MTMMF)

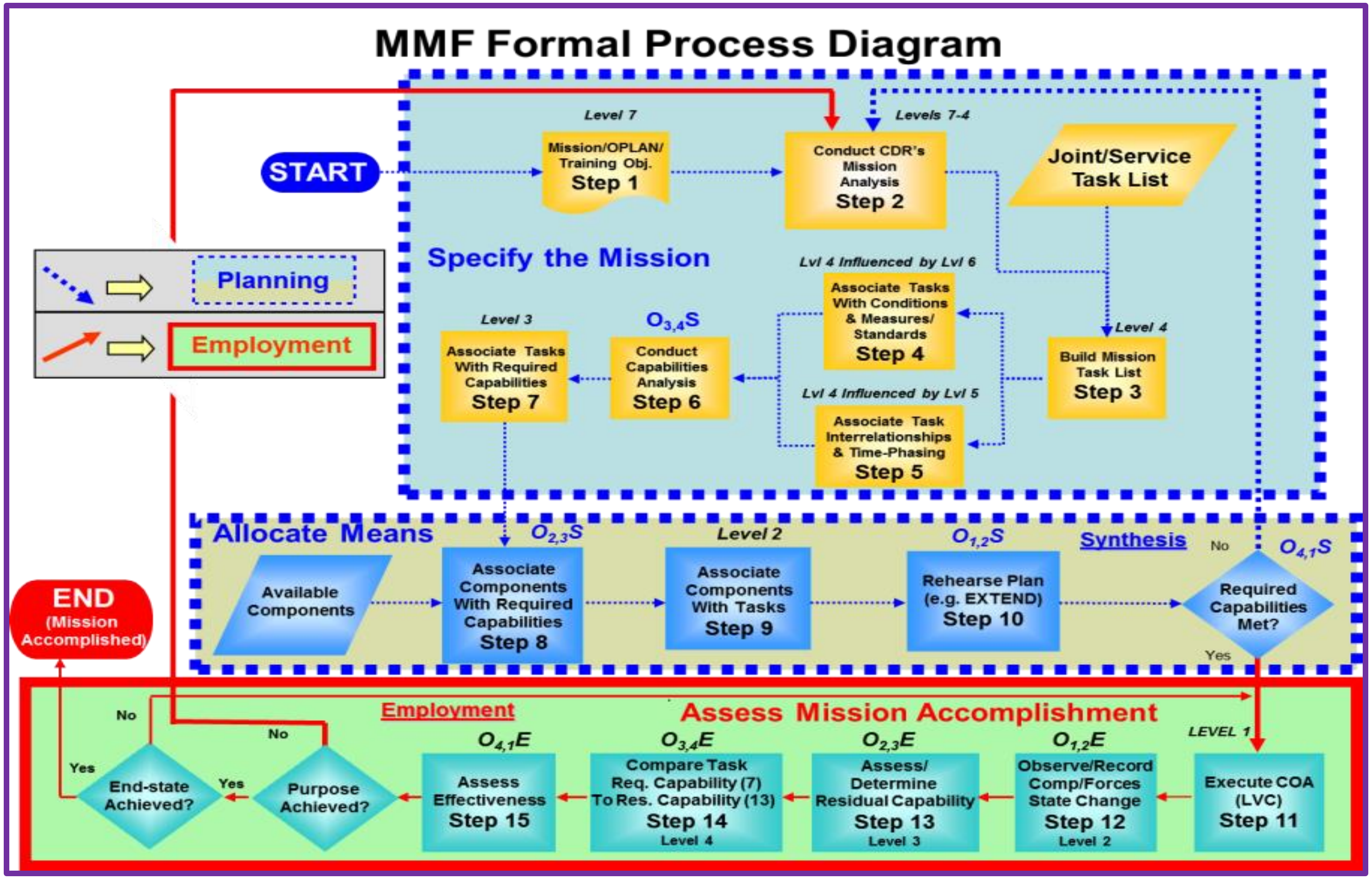


Diagram Showing the Detailed Relationships Between Level-5 (Index, Location & Time) and Level-6 (Context, Environment) On Level-4 (Tasks, Operations) and Level-3 (Functions, Capabilities) [Deitz et. al. May 2006.]

MISSIONS AND MEANS FRAMEWORK (MMF) and the Multi-Threaded Missions and Means Framework (MTMMF)

Consider Slide 25, 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 Slide 25 is an extension of basic MMF model. 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, DESIGN NAVIGATION METHOD (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.

AXIOMATIC DESIGN, DESIGN NAVIGATION METHOD (DNM), AND EXPERIMENTAL DESIGN FOR VALIDATION OF PREDICTED CHOICES AND SELECTION OF PREDICTED CHOICES

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.

AXIOMATIC DESIGN, DESIGN NAVIGATION METHOD (DNM), AND EXPERIMENTAL DESIGN FOR VALIDATION OF PREDICTED CHOICES AND SELECTION OF PREDICTED CHOICES

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.

AXIOMATIC DESIGN, DESIGN NAVIGATION METHOD (DNM), AND EXPERIMENTAL DESIGN FOR VALIDATION OF PREDICTED CHOICES AND SELECTION OF PREDICTED CHOICES

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										

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

AXIOMATIC DESIGN, DESIGN NAVIGATION METHOD (DNM), AND EXPERIMENTAL DESIGN FOR VALIDATION OF PREDICTED CHOICES AND SELECTION OF PREDICTED CHOICES

Slide 30 is based on Design Navigation Method (DNM), an extension of Axiomatic Design [Nakazawa 2001; Nyamekye 2009]. In Slide 30, 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]. 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.

AXIOMATIC DESIGN, DESIGN NAVIGATION METHOD (DNM), AND EXPERIMENTAL DESIGN FOR VALIDATION OF PREDICTED CHOICES AND SELECTION OF PREDICTED CHOICES

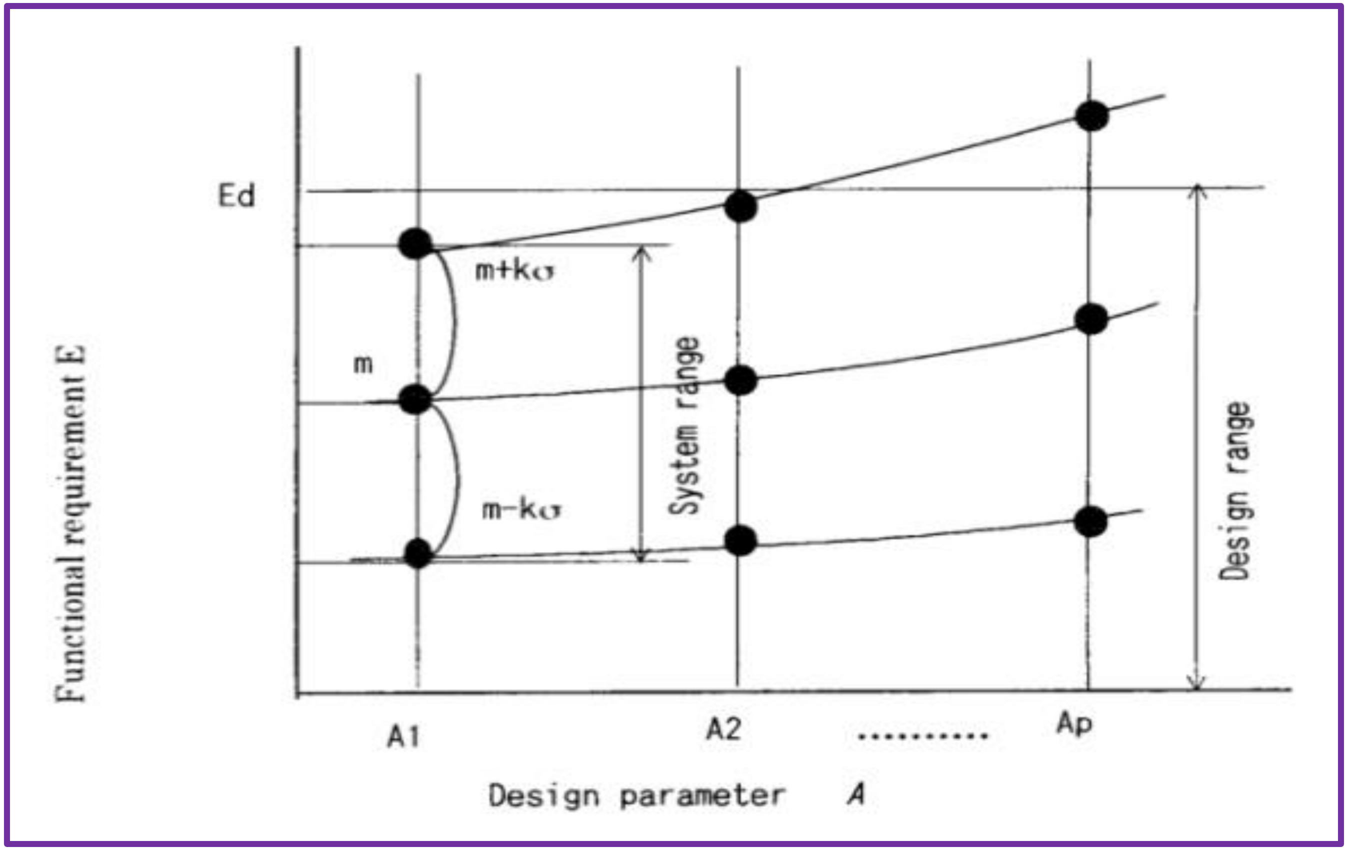
EXPERIMENTAL TEST RUN NUMBER FOR A MISSION TASK (Level-4) FOR A GIVEN ROUTE	FUNCTIONS (Level-3) THAT MUST BE PERFORMED TO EXECUTE A MISSION TASK, AT THE FOLLOWING DESIGN PARAMETERS OR OPERATING VARIABLES, FOR EACH EXPERIMENTAL TEST RUN.					EXPERIMENTAL OR SIMULATION RESULTS FOR FUNCTIONAL REQUIREMENTS (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 CONCEAL MENT (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

Partial Experimental Design Model (From Slide 30), 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.]

AXIOMATIC DESIGN, DESIGN NAVIGATION METHOD (DNM), AND EXPERIMENTAL DESIGN FOR VALIDATION OF PREDICTED CHOICES AND SELECTION OF PREDICTED CHOICES

Slide 32 represents a partial subset of the detailed experimental design model for the OACOK factors. The cells in Slide 32 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.

AXIOMATIC DESIGN, DESIGN NAVIGATION METHOD (DNM), AND EXPERIMENTAL DESIGN FOR VALIDATION OF PREDICTED CHOICES AND SELECTION OF PREDICTED CHOICES



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

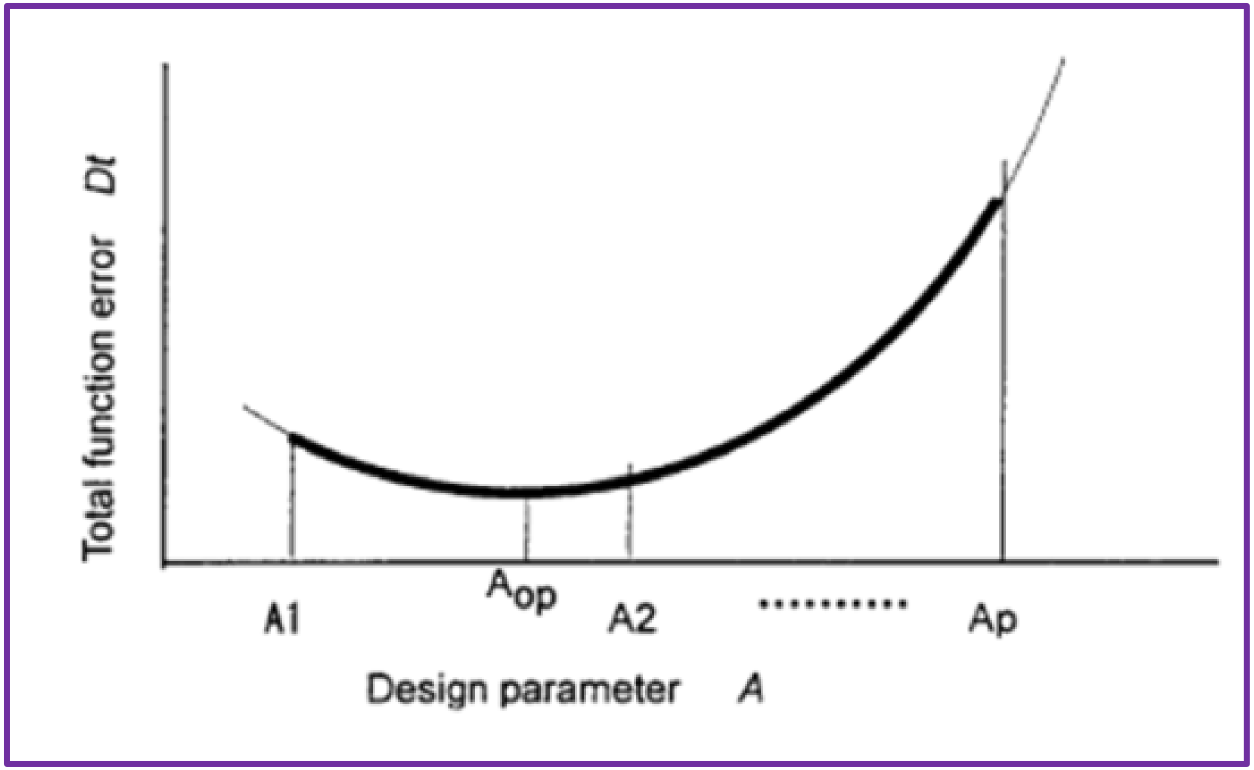
AXIOMATIC DESIGN, DESIGN NAVIGATION METHOD (DNM), AND EXPERIMENTAL DESIGN FOR VALIDATION OF PREDICTED CHOICES AND SELECTION OF PREDICTED CHOICES

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 Slide 34, 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.

AXIOMATIC DESIGN, DESIGN NAVIGATION METHOD (DNM), AND EXPERIMENTAL DESIGN FOR VALIDATION OF PREDICTED CHOICES AND SELECTION OF PREDICTED CHOICES

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 Slide 34. 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 Slide 34.

AXIOMATIC DESIGN, DESIGN NAVIGATION METHOD (DNM), AND EXPERIMENTAL DESIGN FOR VALIDATION OF PREDICTED CHOICES AND SELECTION OF PREDICTED CHOICES



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

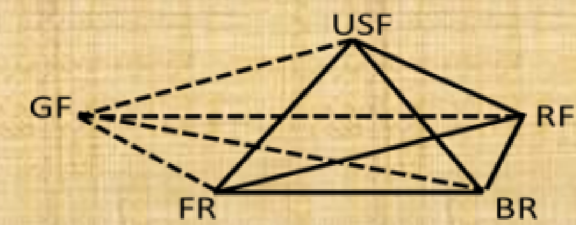
AXIOMATIC DESIGN, DESIGN NAVIGATION METHOD (DNM), AND EXPERIMENTAL DESIGN FOR VALIDATION OF PREDICTED CHOICES AND SELECTION OF PREDICTED CHOICES

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. Slide 37 exhibits the total information content (total function error) curve.

AXIOMATIC DESIGN, DESIGN NAVIGATION METHOD (DNM), AND EXPERIMENTAL DESIGN FOR VALIDATION OF PREDICTED CHOICES AND SELECTION OF PREDICTED CHOICES

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 Slides 30 and 32. For simplicity, we have omitted the details.

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



USF = United States Forces

FR = French Forces

BR = British Forces

RF = Rebel Forces

GF = Gaddafi Forces

<u>Graph Model for the Libyan Conflict</u>:

<GF> + <USF, FR, BR, RF> ;   minimal stratum in "+"; dotted lines represent conflict between subjects; solid lines represent cooperation between subjects.

<u>Polynomial</u>: GF + (USF.FR.BR.RF)

<u>Diagonal Form for Polynomial</u>:

[USF][FR][BR][RF]

[GF]   +   [USF.FR.BR.RF]

[GF + [USF.FR.BR.RF]]

} ← Mental Choice of Subject, e.g., Warfighter

← Group's Influence on Subject, e.g., Warfighter

<u>After Transformation of Diagonal Form</u>:   [GF + [USF.FR.BR.RF]]

Reflexive Game Theory Algorithm for Representation of a Group.

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

Slide 40 depicts the participants in the Libyan conflict. 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.

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

The RGT begins with the definition of the subjects – constituting the *complex endeavors* --, which in this example are, namely, Slide 40: 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, Slide 40, 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 between 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, Slide 40, we then construct the polynomial, Slide 40, 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].

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

The next step is to convert the polynomial into diagonal form, Slide 40. 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. Using the Boolean algebra, we can then transform the diagonal form into a final analytical form (Slide 40).

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

Choice Equation: X = A X + B not (X)
has a solution only if B is a subset of A, that is,

$$A \supseteq B$$

Transform: -- GF + (USF.FR.BR.RF) – into a choice equation for each subject.

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

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

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

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

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

GF = GF + (USF.FR.BR.RF) (GF + not.(GF))
= GF + (USF.FR.BR.RF).(GF) + (USF.FR.BR.RF).not(GF)
= (1 + (USF.FR.BR.RF)).GF + (USF.FR.BR.RF).not(GF)
= GF + (USF.FR.BR.RF).not(GF)

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

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

Using the Boolean algebra, we then simplify the final analytical form (Slide 40) to obtain the generic choice equation for each subject, Equation 1, (same equation in Slide 44), and check if the choice equation has a solution, Equation 2, (same equation in Slide 44).

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 46 shows the details.

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

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}

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

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

Consider the matrix of influence. 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 – { α } --, deploy ground troops { β }, arm the rebels, { γ }, Gaddafi leaves power { μ }.

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 { α }, deploy ground troops { β }, arm the rebels { γ }, Gaddafi leaves power{ μ }.

Furthermore, the British Forces (BR) influenced the Rebel Forces {RF} to arm themselves { γ }, and influenced Gaddafi to leave power { μ }.

Each column represents the influence that the other subjects exert on the subject.

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

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

USF = $(\{\tau\} + (\{\delta\}.\{\delta\}.\{\delta\})$.USF + $\{\tau\}$.not(USF) = $(\{\tau\} + \{\delta\})$USF + $\{\tau\}$.not(USF) = $\{\tau,\delta\}$ USF + $\{\tau\}$.not(USF);

B= $\{\tau\}$; A = $\{\tau,\delta\}$; USF makes a choice at least between $\{\tau\}$ and $\{\tau,\delta\}$. **USF chooses $\{\alpha, \mu\}$.**

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

BR = $(\{\tau\} + (\{\eta\}.\{\delta\}.\{\delta\}))$.BR + $\{\tau\}$.not(BR) = $(\{\tau\} + \{\eta\})$BR + $\{\tau\}$.not(BR) = $(\{\tau,\eta\}$BR + $\{\tau\}$.not(BR); B= $\{\tau\}$; A = $\{\tau,\eta\}$; BR makes a choice at least between $\{\tau\}$ and $\{\tau,\eta\}$. **BR chooses $\{\alpha, \mu\}$.**

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

FR = $(\{\tau\} + (\{\eta\}.\{\delta\}.\{\delta\}))$.FR + $\{\tau\}$.not(FR) = $(\{\tau\} + \{\eta\})$FR + $\{\tau\}$ .not(FR) =$\{\tau,\eta\}\}$FR + $\{\tau\}$.not(FR);

B= $\{\tau\}$; A = $\{\tau,\eta\}$; FR makes a choice at least between $\{\tau\}$ and $\{\tau,\eta\}$. **FR chooses $\{\alpha, \mu\}$.**

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

RF = $(\{\tau\} + (\{\gamma\}.\{\gamma\}.\{\gamma\}))$.RF + $\{\tau\}$.not(RF) = $(\{\tau\} + \{\gamma\})$RF + $\{\tau\}$.not(RF) = $\{\tau,\gamma\}$RF + $\{\tau\}$.not(RF);

B= $\{\tau\}$; A = $\{\tau,\gamma\}$; RF makes a choice at least between $\{\tau\}$ and $\{\tau,\gamma\}$. **RF chooses $\{\gamma\}$.**

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

GF = GF + $(\{\mu\}.\{\mu\}.\{\mu\}.\{\mu\})$.not(GF) = GF + $\{\mu\}$.not(GF)

= (1)GF + $\{\mu\}$.not(GF);

B= $\{\mu\}$; A = 1; GF makes a choice at least between $\{\mu\}$ and 1. **GF chooses $\{\tau\}$**

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

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

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.

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

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

Slides 48 and 49 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. Of particular importance is Slide 49, 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. The predicted choices were in remarkable agreement with the end results of the Libyan conflict.

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

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".

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.

CONCLUSIONS

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.