The Missions & Means Framework (MMF) Ontology: Matching Military Assets to Mission Objectives

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ABSTRACT

Modern warfare, whether focused on kinetic, information gathering, or combinations of both missions, is based on many task sequences executed by numerous OWNFOR and OPFOR entities. To frame the complexity of warfare, professional warfighters have for many years followed the Military Decision-Making Process (MDMP). By this approach, mission tasks (with conditions and standards) are used to identify requisite capabilities. Only then are appropriate entities assigned to task execution. What emerges is a clear logical linkage from mission (i.e. tasks) to capabilities to materiel. In 2003, the Missions & Means Framework (MMF) was developed as a formal embodiment of the MDMP.

Unfortunately, in many materiel studies, the MDMP is absent as the logical basis for a] specifying explicitly the military mission and b] quantitatively evaluating the mission utility of alternative products and services. Probably the greatest challenge comes in the disciplines of C4ISR supported by ontologies in which formal naming and definition of the types, properties, and interrelationships of the entities are fundamental to characterizing mission success. Underway is a demonstration using the MMF to plan, monitor and assess execution of operational tests and supporting developmental activities. And recently, the study has expanded to support MINI-DASS (Mission-Informed Needed Information-Discoverable, Available Sensing Sources) an ISR information-generating methodology program to make explicit the relationship between Situational Understanding and mission success.

This singular integrating MMF ontology formalism has significant ramifications across a broad group of research, requirements, test, training, and analytic activities all of which are identically mirrored in this single conceptual model.

Keywords: Missions & Means Framework, Military Decision Making Process, Mission Effectiveness, Ontologies, Task Prosecution

1. INTRODUCTION & CONTEXT

Advances in information generation technologies, the acquisition of new sensors and the proliferation of mobile devices result in the production of an overwhelming amount of data and magnifies the challenges to acquire and retrieve relevant information among heterogeneous information sources. In addition, the limited quantity and capabilities of intelligence, surveillance, and reconnaissance (ISR) resources to process multiple requests for information collection creates the necessity for maximizing their utilization in order to increase the value and timely delivery of the information gained. Situational understanding is needed for both ISR and kinetic force-on-force military operations.

The increasing number and diversity of both information sources and kinetic assets makes operations more and more challenging; this is especially true in a coalition environment. Not only are ISR and kinetic assets more disparate, but coalition operations are usually ad hoc and highly distributive. In addition, disparate coalition policies make joint operations even more challenging.

In the context of this paper, an ISR asset is any information source, producer or container that can deliver information to consumers (analysts, planners, decision makers). It can be a physical sensor, a human source from which data can be collected or an information container (e.g. database) from which information can be retrieved.

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Figure 1 shows a high-level externalization of the process for obtaining information for situational understanding [1].

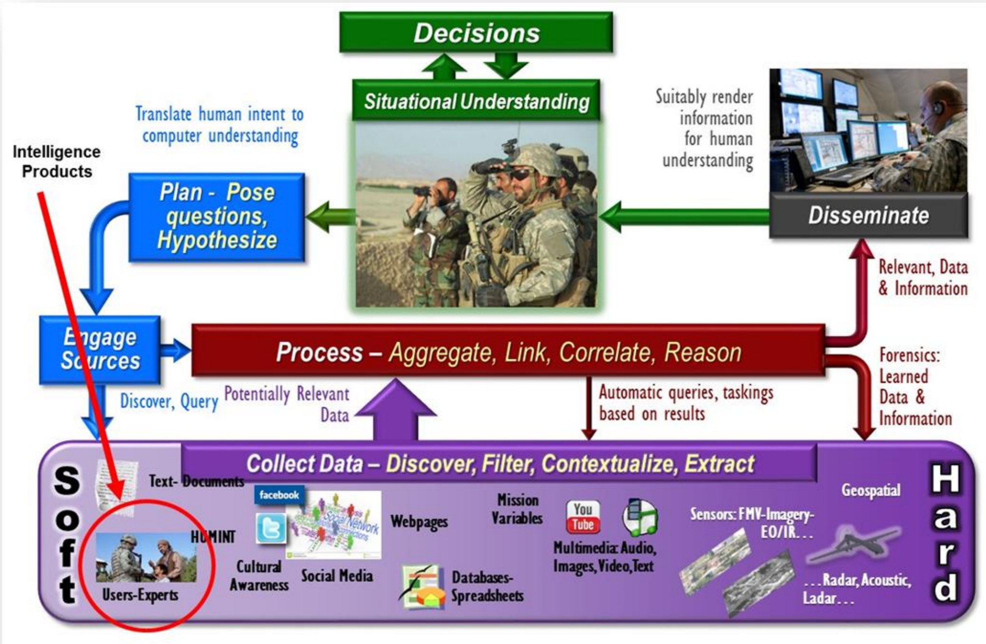

Figure 1. A representation for obtaining relevant information for situational understanding.

The cycle starts with the need for situational understanding to inform a military decision. A mission-driven query for information is initially generated. A man-machine interface is needed to translate the request so the computer can understand it. The mission-relevant data/information sources must then be engaged; they need to be discovered and then queried. To collect the necessary mission-relevant data/information, the information needs to be filtered for relevancy and then extracted. This extracted data/information may then be processed with various data analytic capabilities including fusion, correlation, aggregation, etc. Information then may be exploited, perhaps by an analyst, and disseminated to the consumers of the information including the decision makers. The key elements of the representation are:

- Information queries that must be tied to a particular mission/task
- Machine understanding of needed information
- Discovery and availability of information sources (ISR assets)
- An information-based hierarchy of assets, including:
    - Fusion engines
    - Information processing techniques (including PED, Processing, Exploitation & Dissemination)
    - Intelligence Products
- Need externalization of situational understanding
- Functionality to match capabilities *provided by means* to capabilities *required by a mission*

This externalization illustrates the variety of ISR assets to be collected, exploited, processed, analyzed, and disseminated for enhanced situation awareness and decision making. Optimizing the discovery and utility of coalition ISR and kinetic assets when facing multiple requests for information and enhancing the data to decisions process by gathering mission-relevant information for consumers will require automated tools in support of collection planning and assessment.

Research for the development of sensor ontologies providing rich semantic descriptions of sensor capabilities and properties has demonstrated benefits for sensor integration, ISR resource tasking and information fusion. Efforts in this area can be leveraged as a foundation and extended to meet the requirements of our research. In our work, in addition to developing representations of sensor properties, capabilities and availability, we are developing formal representations of different types of information produced by disparate information sources and how they help fulfill information gaps. High-level information requirements need to be decomposed into specific information requests and expressed according to concepts of these ontologies, to facilitate the matching of requirements to appropriate information sources. These models, combined with appropriate reasoning schemes, will improve current processes.

The U.S. Army Research Laboratory (ARL-SEDD, -CISD, and -SLAD) and AMSAA are conducting related research efforts on the optimization of the utility of ISR and kinetic assets to meeting mission needs. This research effort is focused on developing a Missions and Means Framework (MMF) for optimizing the utilization of available ISR and kinetic assets (means) to the information needed in an operation (mission). These thrusts are intended to enable enhanced situational understanding.

This paper describes the processes and models involved in the generation of a mission build and the required capabilities needed as well as the development of an ontology that can enable the ability to ascertain what assets are available and what capabilities they can provide to meet mission capabilities needed. For purposes of this paper, the terms *data* and *information* are used synonymously.

2. THE MILITARY DECISION MAKING PROCESS

We now turn to the professional warfighter (or operator) to see how virtually all missions across the Range of Military Operations [2] are developed, prosecuted, and assessed.

2.1 How are Missions Prosecuted? Introduction to the MDMP

Missions are often developed to deal with extremely complex problems, especially at higher echelons. Decision makers and their staff must find a way to visualize such missions. They must be able to structure the mission, analyze it, develop and analyze potential courses of action to accomplish it, and assess progress during execution. In these situations, military leaders apply the process of Design Methodology (DM) to compare an existing set of conditions to the desired end state. They then visualize the obstacles standing in the way and develop a conceptual approach to overcome the obstacle(s) and achieve the end state. Once a mission has been derived or issued from higher headquarters, the Military Decision-Making Process (MDMP) [3] is used as the underlying framework to analyze, plan, structure, organize, and assess mission execution. The MDMP is a seven-step process. For the purposes of this paper we will summarize key portions of the first four steps which describe how missions are analyzed and plans are then developed to accomplish them. See Army Tactics and Techniques Publication (ATTP) 5-01 [4] for a more detailed discussion and explanation of DM, MDMP, and the interrelationship between them.

Step 1 – Receipt of Mission

- Unit receives mission from next higher echelon or derives mission from analysis of operational environment

Step 2 – Mission Analysis

- Analyze mission and higher commander intent to identify specified, implied and essential tasks
- Essential tasks form the basis for unit's restated mission
- Specified and implied tasks incorporated in commander's intent and course of action. Some form basis for tasks to subordinate units and become their directed mission.
- Other key outputs include initial Commander's Critical Information Requirements (CCIRs) (information required by the decision maker during planning and execution), Essential Elements of Friendly Information (EEFIs) (information sought by adversary about friendly forces), and Assumptions.

Step 3 – Course of Action (COA) Development

- Develop two or more potential COAs to accomplish the mission.
- Goal is a combined arms concept with cohesive set of actions to produce effects needed to achieve mission end state.
- Products are COA statements and sketches describing the *who* (force structure), *what* (tasks), *when*, *where* and *why* (purpose) for each subordinate unit.

Step 4 – COA Analysis and War gaming

- Analyze to identify potential difficulties/coordination problems and probable consequences of planned actions.
- War game to visualize flow of operations given own force strengths and dispositions, threat capabilities and possible COAs, and other aspects of the situation.
- Analyze each event and identify tasks the force must accomplish one echelon down, using assets two echelons down.

2.2 Use of Formalisms to Describe MDMP Products

The MDMP guides the planner through mission analysis and plan development. It provides the tools to assess progress against mission objectives during execution. Missions and the plans developed to achieve them are stated in terms of tasks and desired results. Tasks provide the common language needed to specify what actions have been assigned in the mission statement and what actions must be performed as part of the plan developed to accomplish the mission. Task names and descriptions must be commonly understood by warfighters and supporting organizations. Recognizing this, the U.S. Military established the Universal Joint Task List (UJTL) [5, 6] to specify and provide doctrinally-based task descriptions (along with common descriptors for environmental Conditions and Standards) from the Strategic National (i.e. National Command Authority) down through the Operational level-of-war for tasks performed by joint (two or more services) forces. Each Service then developed its own universal task list to specify and describe tasks commonly performed by individuals and organizations within that service. These tasks are typically used to describe missions and tasks performed at the tactical level-of-war by service-pure organizations (e.g., Army battalions, Navy ships, Air Force squadrons, etc.) in support of UJTL tasks performed as part of Joint campaigns and operations. The Army developed the Army Universal Task List (AUTL) [7] 'to provide a common doctrinal structure for collective tasks that support Army tactical missions and operations conducted by Army units and staffs'. Collective tasks are defined in Army Doctrinal Reference Publication (ADRP) 1-03 as 'clearly defined, observable and measureable activities or actions that require organized team or unit performance leading to the accomplishment of a mission or function'.

We suggest that doctrinal planning and decision-making processes such as the MDMP, when used to define and instantiate a mission, can serve as a highest-level defining state space. The Joint Capabilities Integration Development System (JCIDS) is at least implicitly based on this premise. The Requirement Identification and Document Generation phase of the JCIDS process directs Services, Combatant Commands, and other DoD Components to "conduct Capabilities Based Assessments (CBAs) or other studies to assess capability requirements and associated capability gaps and risks . . . the assessments are informed by high level strategy and guidance in the National Security Strategy, National Defense Strategy, National Military Strategy . . ." It continues by stating that ". . . capability requirements and capability gaps identified through CBAs and other studies are traceable to an organization's assigned roles and missions, and, to the greatest extent possible, described in terms of tasks, standards, and conditions. . . " [4] Joint Publication 3.0, Joint Operations, dated 11 August, 2011, defines conditions as 'those variables of an operational environment or situation in which a unit, system, or individual is expected to operate and may affect performance' [2] CJCSM 3500.04F, the Universal Joint Task Manual, dated 1 June 2011, defines standards as 'quantitative or qualitative measures for specifying the levels of performance for a task' [6]. When informed by key reference missions (including Joint and Service concepts), the MDMP should serve as the single integrating framework for the Defense community.

2.3 The MDMP as a Formal Structure

MDMP assumes an advanced level of familiarity with military doctrine and doctrinal terms and graphics. It focuses on development and production of outputs (briefing charts, plans and orders, etc.) to convey results of mission analysis and planning to military decision-makers, staffs, and executing organizations. These outputs are hard for military novices to understand and apply. Little-to-no documentation of the detailed thinking, discussions, and sub-processes that lead to MDMP outputs is provided. When it does exist, the same community-specific language not commonly understood in the larger DoD community is used.

Since tasks at higher levels of war inform lower levels, there is a top-to-bottom traceability, somewhat akin to a mathematical mapping which (inferentially) projects higher-level information to lower levels. This inferred higher-to-lower mapping can serve to identify which metrics at the same level-of-war are derived from (and therefore share a common heritage with) metrics at levels above. Through these mapping relationships, when properly applied, both necessary and sufficient metrics can be identified and shared, and exclusionary uses of the same metric in different subspaces is illuminated. The MDMP structures multiple levels of war and does so by linking tasks both horizontally (at a given level-of-war) and vertically (by level-of-war). The supporting abstractions for these notions will be shown later in the paper. **Figure 2** illustrates what happens, for example, when the MDMP is used to analyze a Military Operation in Urban Terrain (MOUT) mission [8]. It results in sequences of tasks hierarchically structured by level-of-war, ultimately from the National Command Level down to the Tactical Atomic.

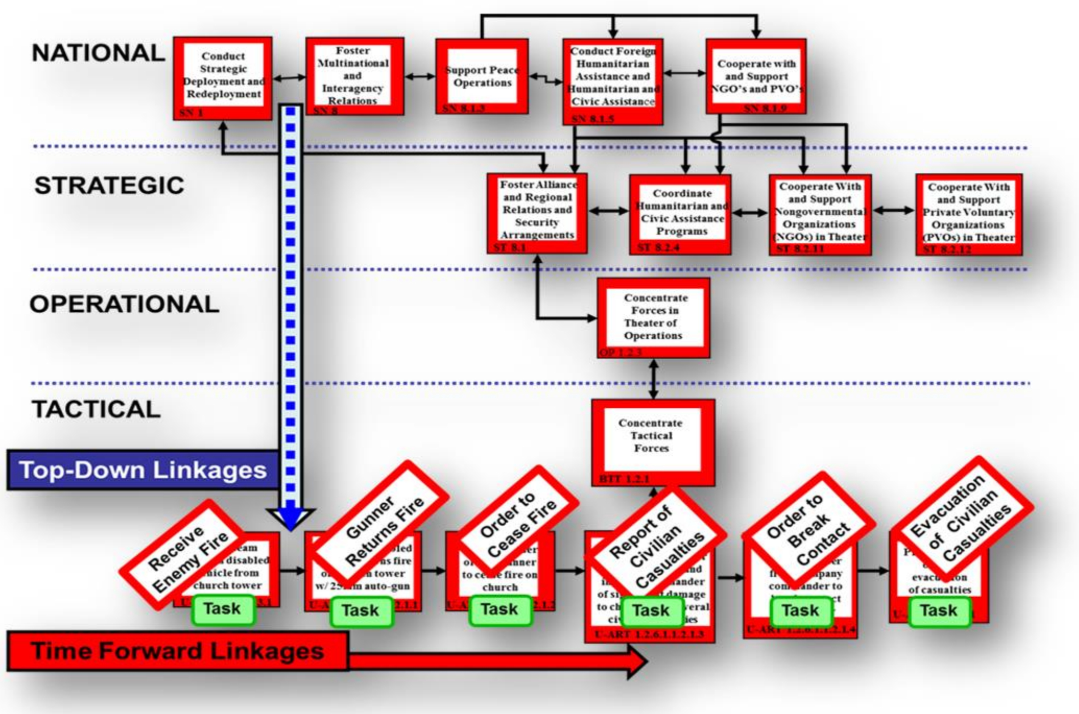

Figure 2. Part of a MOUT mission layout by level-of-war [8]. In general, the higher-level tasks are defined and portions passed to lower levels for either execution and/or further decomposition. The dashed blue line represents the top-down inferred relationships. The red arrow indicates time forward.

With so much at stake, we suggest the following approach:

- Require a Defense-wide framework, language, and processes common to and shared by all participants.
- Establish the pieces and how they fit together.
- Resolve and extend semantics and syntax issues; task lists represent only a part of requisite shared language.
- Identify objective elements; facts, are inherently quantifiable.

- Identify subjective elements; expert opinion, particularly as related to mission effectiveness, must nevertheless be framed using quantitative discipline.
- Start with the mission, since it's about mission success.
- Ensure that missions underpinning the DoD enterprise support functions are contained in high-level strategy and guidance, joint and service concepts, and urgent operational needs (UONs) from combatant commanders.
- Begin requirements identification with application of a common framework to concept analysis and the initial identification of capability gaps and risks.
- Use a common framework to enable effective integration across enterprise stove pipes through early collaboration, in depth understanding of the logic and context behind requirements, greater vertical and horizontal transparency, and a logical structure for storing, organizing, accessing, and updating requirements data across system life cycles.

3. THE MISSIONS & MEANS FRAMEWORK

Work on what has come to be known as the Missions & Means Framework (MMF) began about 2000. The MMF [9, 10] evolved from prior ballistic live-fire simulation [11], the Task Lists construct, and additional requisite context information necessary to define, structure, and monitor warfare execution. These efforts resulted effectively in a framework that can serve as an analytic surrogate for the MDMP. The full MMF has been discussed elsewhere, so the description here will be brief.

3.1 Task Cycles

In this section, we describe the MMF in a bottom-up fashion. At the heart of the MDMP and its formalism as reflected in the MMF is the explicit processing of tasks. **Figure 3** illustrates an example of a Task Cycle. We start by representing a task executed by friendly forces (**OWNFOR**). **Level 4**, shown in green, represents a particular task.

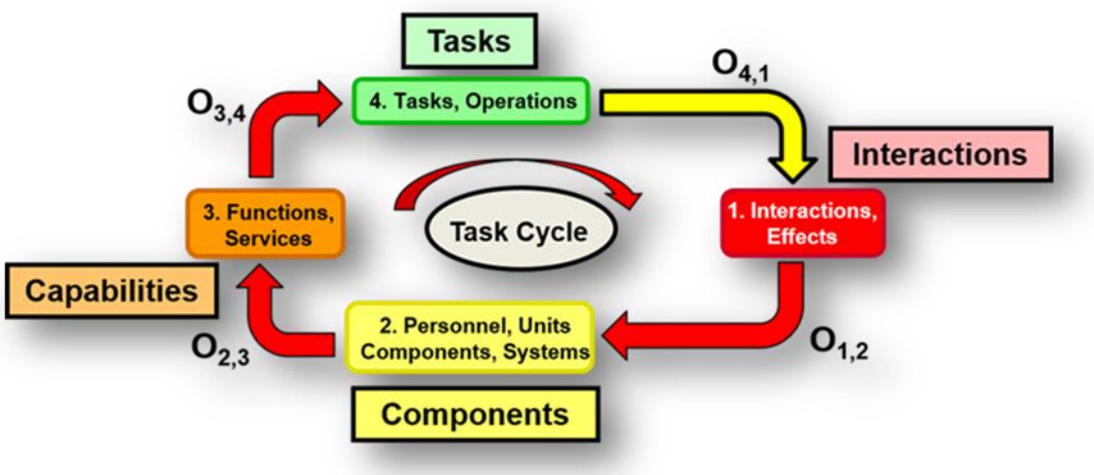

Figure 3. An illustration of a Task Cycle. A task at **Level 4** initiates an interaction at **Level 1** via the **$O_{4,1}$ Operator**. The **$O_{1,2}$ Operator** changes the state of the components at **Level 2**. A new capability is computed at **Level 3** and then finally compared with the capability required for the next task in the cycle at **Level 4**. If the current capability at **Level 3** meets or exceeds that called for by the next task, the process continues. One Task Cycle (i.e., one 360◦ cycle) from initiation to final capability/task comparison via the **$O_{3,4}$ Operator** might represent a single Developmental Test or a single ISR task.

Moving clockwise (time forward), the $\mathbf{O_{4,1}}$ Operator links to a particular class of interaction represented by **Level 1**. The examples discussed earlier were ballistic, but can actually be based on a wide variety of phenomenology. The $\mathbf{O_{4,1}}$ Operator when called repeatedly acts to call elements of a time-ordered event list, commonly used in simulations to organize a sequence of events. Based on the class of interaction called at **Level 1**, the $\mathbf{O_{1,2}}$ Operator causes changes to the people/materiel represented at **Level 2**. Interactions can either be "negative" (causing damage) or "positive" (fixing damage). See **Table I** for examples of a broad class of interaction mechanisms.

Table I. Examples of Interactions per **Level 1** in **Figure 3.**

Ballistic Damage	Jamming	Cyber
Asset Reprogramming	Social Network Scanning	Natural Language Query
Damage Repair	Chemical Attack	Resupply
Laser Damage	Sleep	Directed Energy
Nuclear Damage	Physics of Failure	Logistics Burdens
Reliability	Fair Wear & Tear	Fatigue
Heat Stress	Data Fusion	Spoofing
Sensors/Systems/Processing	• • •	• • •

The $\mathbf{O_{2,3}}$ Operator takes a new state of **Level 2** and maps it to its (new) corresponding capability. The geometry representing complete platforms (both external armor and interior components) has been characterized by BRL-CAD® [12, 13] for many years. Key to the analysis of Vulnerability/Lethality (V/L) interactions, to name just one type, is that not only is it required that the component geometry be represented, but it is also required that the members of assemblies by supporting function (firepower, mobility, communication, etc.) must be described in fault trees. Such trees underwrite the extent to which components are critically vulnerable or have supporting/backup support. When these trees are properly structured, the damage state of the systems of components can be used to estimate the specific platform level of performance in a continuum from fully functional to nonfunctional. **Figure 4** illustrates geometry framed with notional fault trees.

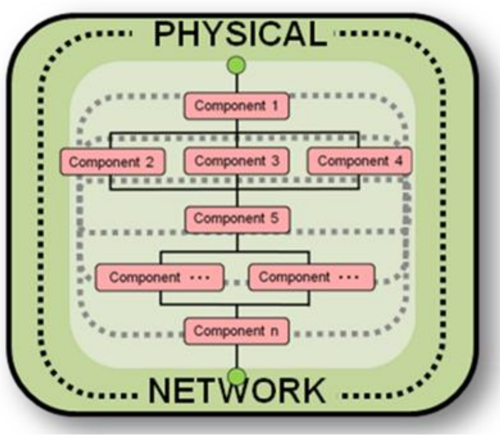

Figure 4. Illustrating component networks at MMF **Level 2**.

After a new capability at **Level 3** is estimated, it is then compared to the **Level 4** by the $\mathbf{O_{3,4}}$ Operator, where a comparison is made between the capability called for in the task (i.e., one element of the mission requirement), and the current capability of the materiel represented at **Level 2**. One complete revolution can be termed a Task Cycle. Multiple Task Cycles can be sequentially and simultaneously linked to execute a set of tasks in a mission thread. Sequential Task Cycle linkages can be created based on a logical timeline generated during the planning process. Military planners, for example, apply planning factors (e.g., average convoy speed on paved roads) to estimate time required for task execution under varying condition sets. Wargaming and mission rehearsals are also conducted to identify and establish conditions–based linkages (e.g., refueling must occur before convoy continues movement). Simultaneous linkages normally occur when there are dependencies between tasks. Depending on the operational conditions, planners may determine that convoys only occur simultaneously with surveillance and reconnaissance of the route to minimize the risk of ambush or improvised explosive device (IED) attack during movement.

3.2 Interactions between Forces

We now build on the structure of **Figure 3** to place an opposing force (**OPFOR**) against the friendly forces (**OWNFOR**). The MMF diagram of **Figure 5** shows two competing forces with the time-forward operators. We want to describe the four basic variants of task execution. **Level 1**, Interactions, is shown outside of the force descriptors since they are "owned" by no one, but are defined by the laws of nature.

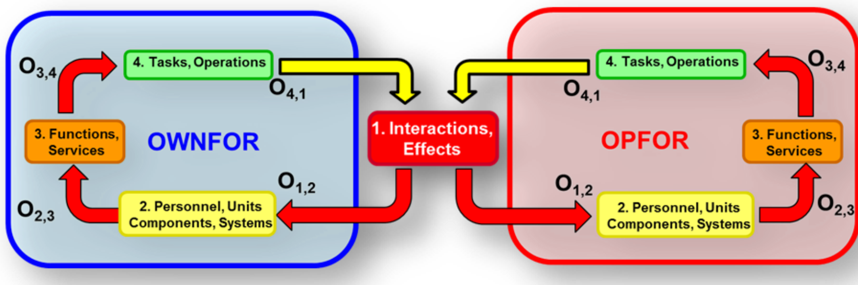

Figure 5. The opposing forces of MMF are shown with the time-forward operators. Note the OWNFOR (time-forward) operators move clockwise; the OPFOR move counterclockwise.

When tasks are initiated by a force, they can be of two forms. Starting from the left in **Figure 6**, the **OWNFOR** can be self-directed, initiate a task on itself - operating a vehicle for example, causes depletion of fuel. The second variant is an **OWNFOR** task and may be outward directed, initiated against the **OPFOR**. An example here is a blue vehicle firing upon a red target. The task initiated by the **OWNFOR** changes the state of **OPFOR** materiel. The third and fourth variants show the two cases for the **OPFOR**. In point of fact, tasks can be initiated on one's own force without causing an interaction with the enemy. However, it's hard to imagine how one side can initiate a task against the opposition without having some effects on itself. A shot from one side to the other may cause target destruction, but it also depletes the ammo stores for the side initiating the interaction. Outward-directed interactions may also generate effects on other entities and on elements of the commonly shared **Level 6**, operational environment, to be described below. These effects may be intentional or unintentional. For the purposes of this paper, we are focusing on effects that result in state changes to **OWNFOR** and/or **OPFOR Level 2** materiel/people.

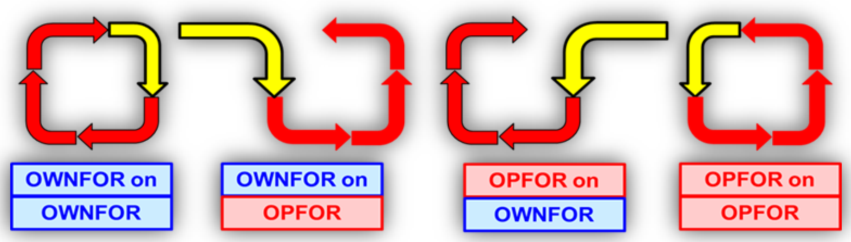

Figure 6. Two kinds of tasks, self-directed (the two outer diagrams) and the two outward-directed (the two inner diagrams).

3.3 The Full MMF

Depicted in **Figure 7**, the full MMF is constituted by eleven fundamental elements; seven levels and four operators. The top three levels (**Levels 5-7**) are used to describe the Mission context in terms of what is to be accomplished and why (**Level 7**); under what environmental conditions (**Level 6**); and when and where (**Level 5**). Data to be stored and organized using these three levels include the results of the Mission Analysis step of MDMP described in **Section 2**. Once a mission has been received/derived and analyzed, the COA development and analysis and wargaming steps of the MDMP are applied to guide the process of developing a plan of action to accomplish the mission using the means available. The remaining four levels (**Levels 1-4**) and the four operators are used to describe the means as illustrated in **Figure 7**

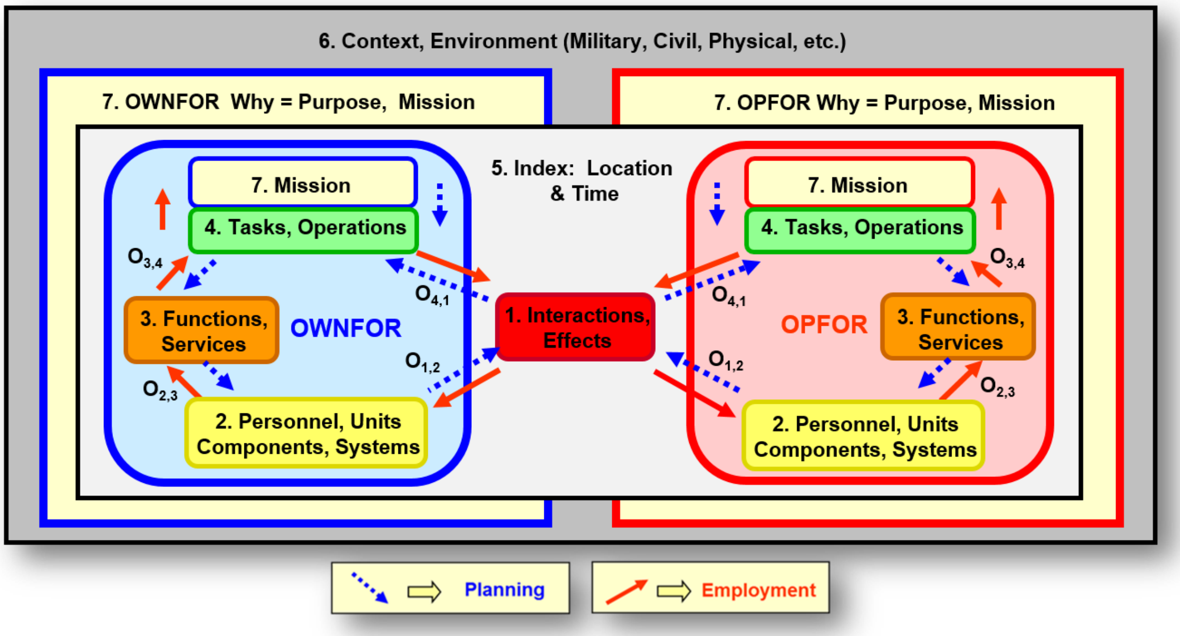

Figure 7. The full Missions & Means Framework. The MMF is characterized by eleven fundamental elements: seven levels and four operators.

Note that **Levels 5** and **6** represent a portion of the mission context that is shared by all entities as represented by the **OWNFOR** and **OPFOR** boxes in **Level 5** even though each entity may have its own unique **Level 7** mission and plan of action (**Levels 1-4** with operators). The appearance of **Level 7** above **Level 4** for both sides represents the normal practice of "restating" the mission externally imposed by a higher authority into a mission statement for the executing entity. Recall from **Section 2** that specified and implied tasks at the higher echelon may become tasks to subordinate units. Those tasks in turn become part of the directed mission for those units initiating MDMP Step 1. Subordinate units analyze the directed mission (MDMP Step 2), identify specified, implied and essential tasks and the essential tasks form the basis for their "restated" missions. This is also a key aspect of establishing the vertical linkage between military echelons (e.g., company, battalion, brigade, etc.) and levels-of-war (i.e., tactical, operational, strategic). The red arrows represent time-forward operators which link the **Levels 1** through **4** in a time-forward sequence as operations are executed in live, virtual, or constructive fashion. The dotted blue arrows represent the time-backward (or top-down) planning actions performed by mission planners during course of action development, wargaming, and mission rehearsal.

We make some observations concerning the levels of the Task Cycle. As illustrated in **Figures 4** and **5**, we note that the materiel components and capabilities are predominantly objective factors and measures. Material elements are inherently physical and measureable; however in application to cognitive issues, they may be primarily subjective. Tasks are inherently subjective; they are conceptualized by the mission planner and are fundamentally a matter of judgment. Interactions, when called in the time-forward (red arrow) execution mode under test, are inherently objective in that they can be observed and their combined effects can be measured. They obey the laws of physics, biology, and, to a lesser degree of certainty, psychology, and may therefore be typically objective. Interactions identified in the planning mode may also be subjective in that they arise from subject matter expert prediction or model/simulation results of task execution.

See **Appendix A** for additional details and applications of the MMF.

4. DEVELOPING AN ONTOLOGY FOR THE MMF

By definition, the Missions and Means Framework provides a formal structuring to the Military Decision Making Process for benefit of military planners and operators. The MMF model is viewed as making a first step toward formally organizing domain knowledge for mission planning and execution. This added formalism makes MMF useful for developing tools and software for military mission planning and simulation and modeling the mission space for detailed understanding of mission requirements. However, toward enabling support for software systems, additional work becomes necessary to establish machine-interpretable encodings for both MMF and its corresponding domain knowledge.

Ontologies, as defined in the information sciences, provide encodings both formal and machine-interpretable domain knowledge. Furthermore, current ontology design practices – as reflected in the Semantic Web research community – actively promote the integration of heterogeneous domain content, via the use of general-purpose (or "upper-level") ontologies. It is our view that MMF could be viewed as an "upper-level" ontology for integrating domain knowledge corresponding to mission planning and execution (i.e., corresponding to the seven MMF Levels). As a first step toward this vision, this section discusses an ontology design corresponding to the full MMF model discussed in **Section 3.3**, and reviews how it may be applied toward domain knowledge integration. It should be emphasized that the presented ontology design is given in an implementation-agnostic manner. In turn, MMF ontology implementations through current (e.g., the Web Ontology Language (OWL)) and future ontology languages will be provided in separate reports.

4.1 Components of Semantic Data and Ontologies

To help frame the discussion on the MMF ontology design, a short review is provided here on common ontology components considered in Semantic Web design practices.

Under Semantic Web publication, graph-based data encodings are commonly used, consisting of four common features: (I) **Classes**, which provide definitions of concepts; (II) **Properties**, which establish relationships between concepts; (III) **Attributes**, which establish attributes of particular concepts; (IV) **Individuals**, which denote specific instances of concepts. Combined, these features are used to define semantic datasets in a graph-based form – in practice, commonly encoded through the W3C Resource Description Framework (RDF) standard.

Graph-based data, encoded through RDF alone, provides limited semantic expressivity to data. Ontologies aim to provide extended expressivity for dataset structuring via use of logic-based constructs for defining classes and properties. Current-generation ontologies are commonly encoded through the Web Ontology Language (OWL), which enables the definition of varying levels of expressivity via usage of Description Logics (DL). Initial efforts to implement the MMF ontology are presently under way, and focus on combined usage of RDF and OWL.

4.2 Related Efforts - The Gomez MMF Ontology

While our effort here represents the first attempt at expressing the full MMF via ontologies, prior efforts have attempted to encode select portions of the MMF for restricted mission planning tasks. Of prior efforts, research conducted in Gomez et al. [14] appears to be one of the more prominent efforts to explicitly consider the MMF model in ontology form. **Figure 8** illustrates a concept map for the Gomez MMF ontology, as well as a color-coded mapping of different components to the greater MMF model.

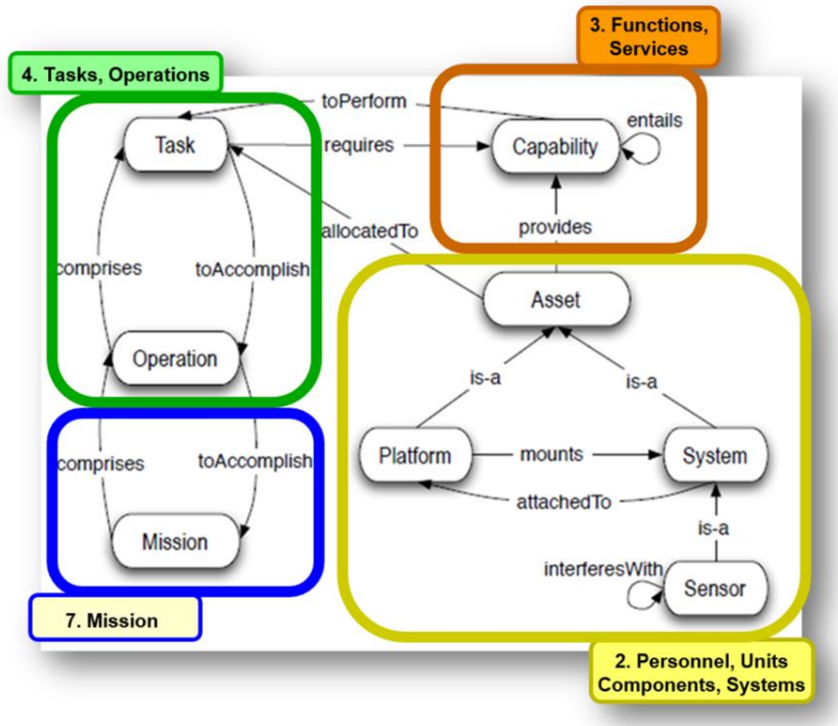

Figure 8. The MMF Ontology as defined by Gomez et al. in [14]. The colored labeling and delineations are provided by the authors of this paper.

Originally, the Gomez MMF ontology was developed in the context of managing sensor assignment to missions – which can be viewed as one of several sub-tasks supported by MMF. As such, a number of key MMF model features appear to be unaccounted for in the Gomez design, including:

(1) Explicit distinctions between MMF synthesis and employment (also known as the stocking and assembly perspectives).

(2) Explicit distinctions for supporting **OWNFOR** vs. **OPFOR** activities, as well as multiple levels of warfare as discussed in **Appendix A**, and illustrated in **Figure A.3**.

(3) Classes and properties expressing Interactions (**Level 1**), as well as Environmental (**Level 6**) and Location/Time Context (**Level 5**).

4.3 Applying Ontologies to MMF Domain Knowledge

As previously considered, MMF represents a generic approach for modeling mission planning and execution, in which specialized domain knowledge becomes necessary for expressing individual levels and operators. As such, MMF presents both generic and domain-specific knowledge modeling requirements.

From a knowledge engineering perspective, different ontologies are expected to be needed for different MMF Levels and Operators. For instance, modeling of MMF **Level 2** components may require usage of a collection of ontologies for expressing different asset types (e.g., Sensors, Vehicles). Therefore, the total domain knowledge required for MMF modeling may span several ontologies – either created with specific mission modeling in mind or reused from third parties. **Figure 9** illustrates this notion with MMF – where MMF corresponds to an upper mission planning ontology, expanded on by domain knowledge for individual Levels.

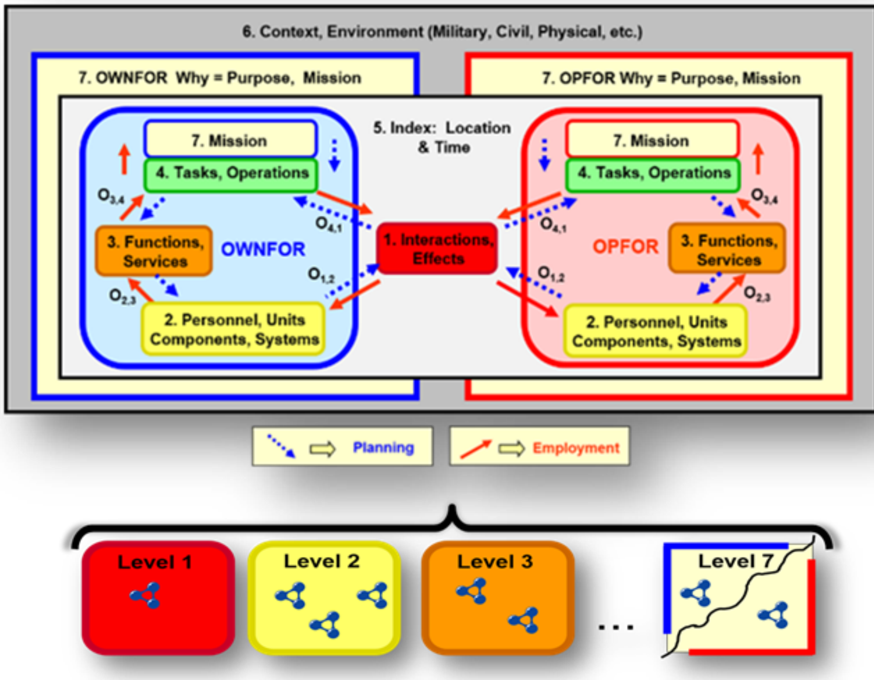

Figure 9. The MMF as both an Upper Ontology and a set of Supporting Ontologies.

4.4 The Full MMF Ontology

To address MMF's need for both formal and machine-interpretable mission encodings, our efforts have attempted to define an ontology for expressing the complete MMF. **Figure 10** presents a conceptual diagram for our MMF ontology, intended to express MMF's complete Level and Operator set from both mission Synthesis and Employment perspectives. For now, our consideration is restricted to modeling only generic MMF model features – i.e., the MMF "upper" ontology. Future work, centered on future applications of MMF in particular, is expected to provide definitions for domain specific knowledge on individual MMF Levels and Operators.

Currently, classes are defined for each of the seven Levels of the MMF model. For each Level, two additional classes are defined: one corresponding to the Synthesis perspective, and another for Employment[1]. Likewise, properties considered include Operators as well as linkages between Synthesis and Employment classes for the seven Levels. Each of the four MMF Operators is encoded as an ontology property, designed to link MMF Levels in both Synthesis and Employment encodings. The notation applied toward naming these properties is as follows:

Op<*Mode*><*Subject*>to<*Object*>

Where the property <Mode> will either be for Synthesis (Syn) or Employment (Emp), and the <Subject> and <Object> will be numbers for appropriate MMF Levels. For example, the property *OpSyn1to2* will correspond to **$O_{1,2}$S** in the MMF notation, Ref. 9, while the *OpEmp2to3* corresponds to **$O_{2,3}$E** mapper in Ref. 9 as well[2].

Additional Class and Property Definitions for the MMF ontology are provided in **Appendix B** and **Appendix C**, respectively.

[1] Definitions for the MMF Synthesis and Employment perspectives are provided in [9].

[2] **Figure A.2, APPENDIX,** shows the Synthesis operators in dotted blue, and the Employment operators in solid red.

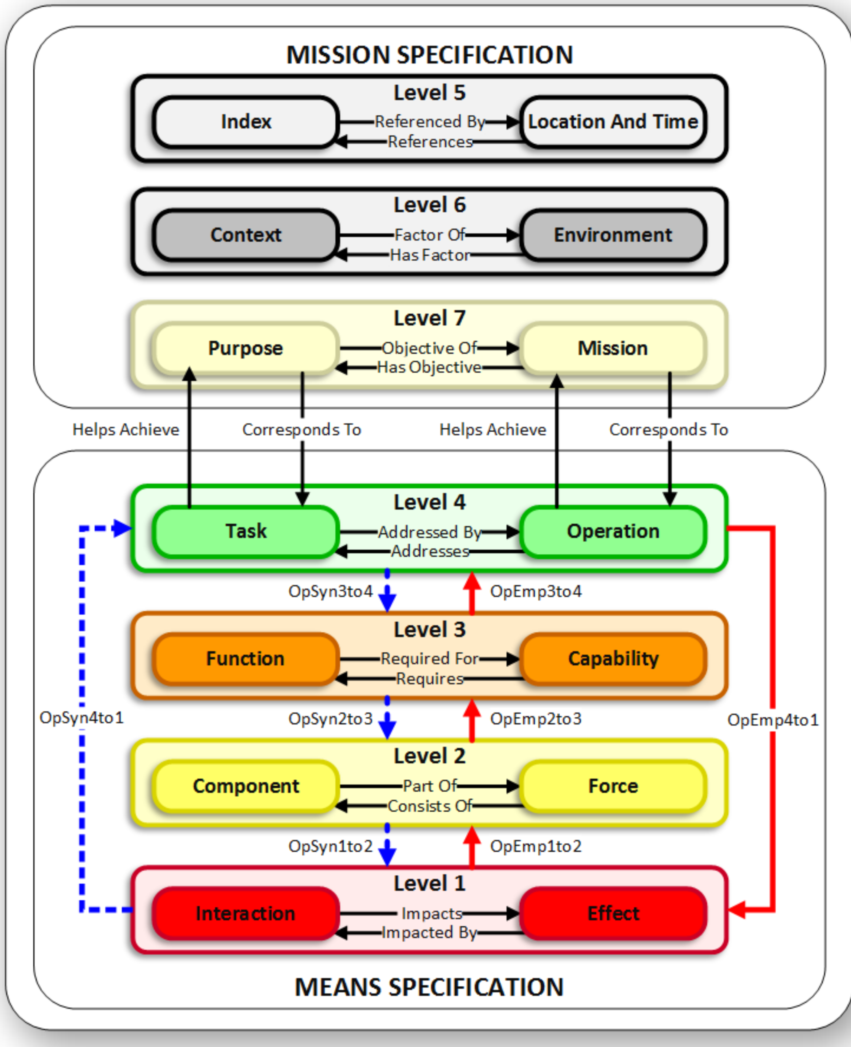

Figure 10. Conceptual Diagram for the full MMF Ontology.

5. PREPARING A COMBAT SIMULATION IN SUPPORT OF BOTH KINETIC AND ISR ACTIVITIES

5.1 MMF for ISR Missions: MINI-DASS

The MMF described above is generic and is applicable to ISR missions where no kinetic actions are involved. ISR missions obtain information to enhance situational understanding so the decision maker can make the best decision possible. There still needs to be a mission build with (**Level 4**) *Tasks* that need to be executed. These tasks require (**Level 3**) *Capabilities* that need to be provided by the (**Level 2**) *Means*. The difference is that the means for ISR missions are available information sources rather than soldiers and weapons. These include means such as sensors, social media, fusion engines and PED process. The (**Level 1**) *Interactions* for ISR missions are also different than for kinetic missions in two respects: (1) the interaction with the OPFOR is passive in that it is information *about* the OPFOR that is needed and (2) the active interactions are with the OWNFOR means in that the ISR means need to be configured (asset C2). It may be noted that a "passive" ISR mission may have a kinetic effect on the OPFOR; e.g., if someone knows they are being observed, they may take an alternative path to avoid surveillance. The utilization of MMF for ISR missions is to provide a mechanism that enhances situational understanding for decision makers.

5.1.1 Key Considerations and Approach

The ultimate high-level goal of MINI-DASS is to provide analytic tools to help provide information for enhanced high-level situational understanding for the decision maker. The application of MMF is to provide the following:

- Common way of describing both requested information from commander and capabilities that can be provided by available information sources (common language)
- Automated capability to enhance understanding in the domains of (1) the environment and (2) the threat
- Framework and mechanism to describe capabilities required
- Automated model of current mission/task building processes

5.1.2 Goals

The key considerations in the application to ISR missions is as follows:

- Information query must be tied to mission/task
- Machine understanding of needed information
- Discovery and availability of information sources (means)
- Determination of mission-relevancy of information
- Information-based hierarchy of assets
- Externalization of situational understanding
- Matching capability of means to mission capabilities required

In applying the MMF framework here, one needs to develop an ontology and models for the information sources. This can be a daunting challenge in that some of the most versatile information sources include social media and the PED process. Both of these sources involve humans, everyday folks in the case of social media and analysts in the case of PED that produce intelligence products and information.

The approach to the development is leverage the existing model and methodology for developing the **Level 4** mission build and tasks as well as the **Level 3** required capabilities. A single overarching scenario has been defined for both the kinetic and ISR missions with several initial use cases having been defined for the ISR missions. We will develop an independent **Level 2** ontology for the ISR asset information source means. In order to determine if MINI-DASS will add value and determine if we are taking the correct approach, we limit the initial information sources to UAS FMV, social media, fusion engines, PED process and traditional low power sensors such as PIR, acoustic and seismic modalities.

5.2 Instantiating the MDMP/MMF

So how does all of this come together in application? We begin with a Use Case in which a unit is conducting wide area security as part of a peace operations mission. Operational SMEs apply the MDMP steps described in **Section 2** to analyze the mission and then develop and analyze the COA(s) to be simulated. The Use Case may already include operations orders/plans with annexes resulting from MDMP application. Further analysis is done to parse the resulting information, identify inter-relationships and organize the resulting information using the MMF levels and operators. **Figure 11** illustrates a portion of the mission-task list generated to capture the MMF **Level 4** for this Use Case.

The resulting information, organized into the MMF Levels and Operators, is integrated and instantiated as task-based mission threads forming the basis for the task cycles discussed in **Section 3**. **Figure 12** illustrates a representative segment of one mission thread for this Use Case. Mission threads such as this capture the results of war gaming the COA. Done properly using data-driven tools such as MS Excel© and MS Project©, mission threads can be continuously updated prior to execution and reused for other analyses.

Essential Tasks from Mission Analysis(MDMP) and Level 7 Task and Purpose Parts			
Task Number	**Task Title**	**Task Description**	**Authoritative Source**
ART 7.5.9	Control an Area	Control requires the commander to maintain physical influence over a specified area to prevent its use by an enemy or to create conditions necessary for successful friendly operations. (FM 3-90-1) (USACAC)	ADRP 1-03, AUTL, October 2015
Other Specified and Implied Tasks from Mission Analysis and Level 4 Task Parts and Operation Packages			
ART 6.4.1	Conduct area and base security operations	Area and base security operations are a specialized area security operation. These operations protect friendly forces, installations, and actions in the support area. They include measures taken by military units, activities, and installations to protect themselves from acts designed to impair their effectiveness. (ADRP 3-37) (USAMSCOE)	ADRP 1-03, AUTL, October 2015
ART 6.4.3	Establish Local Security	Local security includes all measures to protect friendly forces from attack, surprise, observation, detection, interference, espionage, terrorism, and sabotage. ART 6.4.3 enhances the freedom of action of tactical units in an area of operations by identifying and reducing friendly vulnerability to hostile acts, influence, or surprise. (ADRP 3-37) (USAMSCOE)	ADRP 1-03, AUTL, October 2015
ART 6.4.3.2	Establish Check Points	Units establish checkpoints to monitor and control movement, inspect cargo, enforce rules and regulations, and provide information. (ATP 3-39.30) (USAMPS)	ADRP 1-03, AUTL, October 2015

Figure 11. Sample MMF **Level 4**, Mission-Task File.

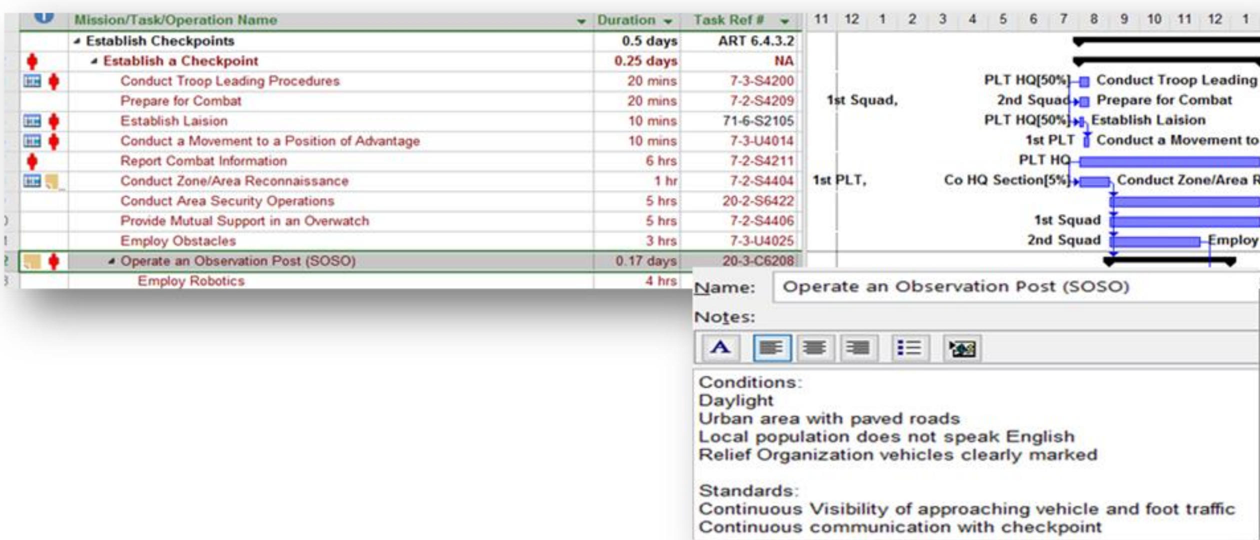

Figure 12. Sample MMF Mission Thread.

6. SUMMARY

As this project is only several months into execution, no definitive results or conclusions can be reached for this particular project goal of ISR information processing. There are prior studies in which the MMF has been used to organize analyses and two in particular have been used to analyze combat simulations [15, 16]. The second of these studies examined detailed company-level action; however the focus was primarily on kinetic effects. The results were a breakthrough in terms of the insights and metrics revealed by these (comparatively) high resolution studies. However, in this past study, the performance metrics were mainly objective. By focusing as we are now in data/information, our attention is on the discoverability/collection/processing/analysis of subjective knowledge. We are attempting something new that, if successful, could have significant impact on military operations. This is the first time that automated tools will actually perform a valid mission and task build for an ISR mission in order to determine what capabilities are needed to execute successfully mission tasks. The automated tools will also determine if the means available and determine the optimal utilization of the means to be applied to the task. If successful, military operators may for the first time have automated tools that actually tie operations to mission requirements as well as have a tool for management of mission assets.

We close by noting that the preliminary work of this project reported here has been to utilize a systematized series of logical structures. In some cases the logical structures have been extant for many years. In the case of the original MMF formalism, the basic structures have existed for 15 years, and just now much new ontological detail is being added. These structures are applied to the missions of the contestants, the tools and individuals who execute supporting tasks, and to the generation of key relevant context information which is key to framing the analysis. In **Figure 13**, we illustrate the sequence of analytic frameworks; we observe that they form an array of nested Venn sets. We believe that the complexity of warfare analysis is such that ad hoc efforts are doomed to fail obviously and may, in fact, even fail when they appear to succeed. It is well-known in complex analytics that one key to success is to understand which parameters are relevant to the issues being examined and must be captured, and which parameters are not relevant and can be excluded. These methods can be thought of as a means for avoiding what are sometimes labelled "ill-posed problems". We trust that the processes we have described contribute to this goal.

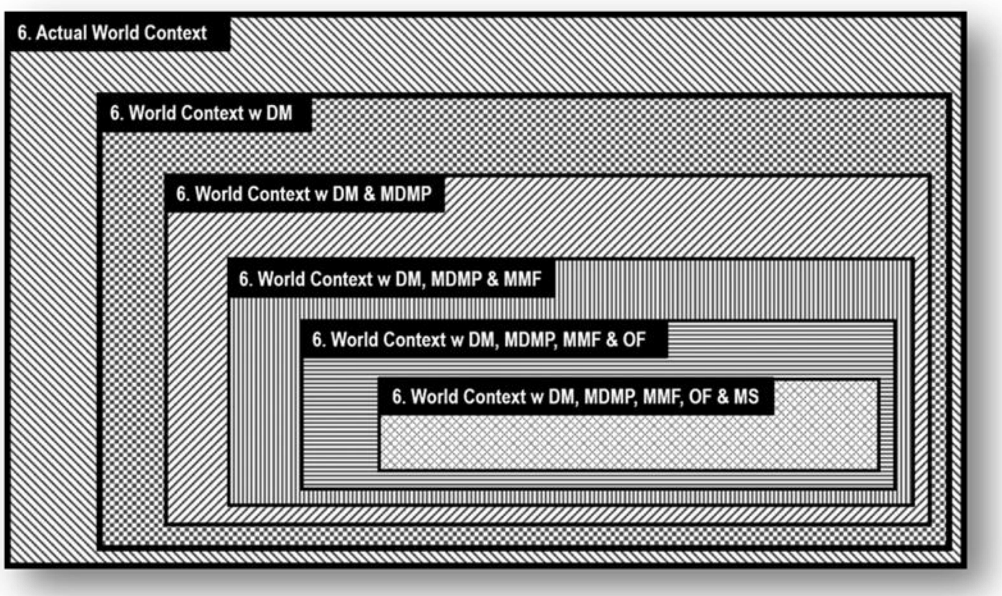

Figure 13. Nested Venn Sets illustrating the reduction of warfighting dimensionality as a sequence of analytic constraints is applied; beginning with the **World Context**, then the (**Perceived**) **World Context** interpreted with **Army Design Methodology** (**DM**), then adding the **Military Decision-Making Process** (**MDMP**), next the addition of the **Missions & Means Framework** (**MMF**), then the application of an **Ontological Formalism** (**OF**), and, finally, a particular **Mission Specification** (**MS**). (Not to scale.)

APPENDIX A

Here we present some additional extensions and implications for the MMF.

A.1 The MMF from a Semantic Perspective

It is important to note that the four levels represented in the MMF, **Figure A.1**, are formed by classes of metrics that are the largest that they can be while still remaining homogeneous as a class.

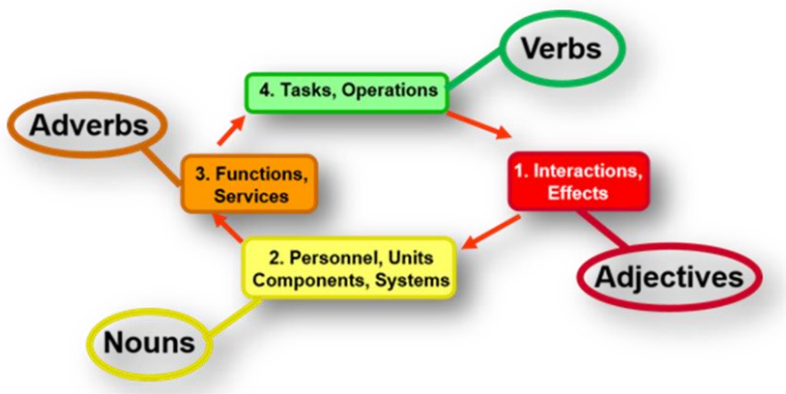

Figure A.1. A semantic interpretation of MMF.

From a natural language perspective, **Level 4**, tasks, can be thought of as verbs, while **Level 2**, materiel, can be thought of as nouns. Composing a mission, like forming a sentence, involves taking nouns and linking them to verbs. But in the MMF structure, the nouns and verbs are not connected directly. They are linked by interactions on one side and capabilities on the other. This retains important flexibility in the paradigm so that platforms, for example, can be modified according to the interactions they have experienced and can be organized according to the capabilities required by tasks to which they are assigned. To take the natural language view further, the interactions may be analogous to adjectives since they modify nouns. And functions (or capabilities) might be thought of as adverbs as they modify verbs.

A.2 The MMF from the Top-Down, Mission-Build Perspective

In **Section 3** the description of the MMF has been from the time-forward or "bottom-up" perspective. This is, of course, how missions are performed. However, in order to build missions, the process must begin with the "end in mind" and work from the end back to the beginning. This process is illustrated in **Figure A.2**.

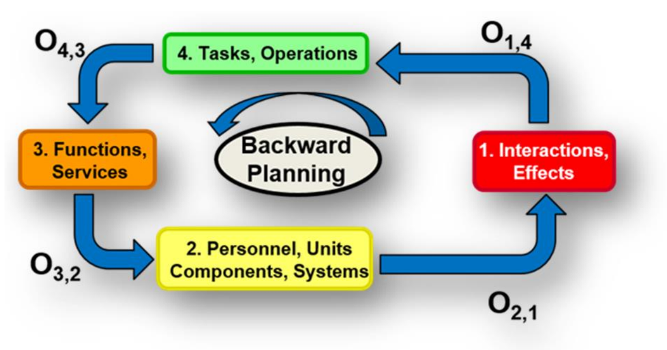

Figure A.2. Developing relevant metrics top down.

Here, based on the mission objectives, the wargaming process is applied to determine the sequence of interactions and desired effects that will achieve the objectives. The tasks most likely to generate wargamed interactions are defined and associated with conditions and standards which in turn determines the requisite capability needed to execute the task. The next step is to define the materiel of choice at **Level 2**, confirm that it has the required capability, and finally look back to the panoply of interactions that may affect the materiel in the context of the mission (due both to **OWNFOR** and **OPFOR** actions). It clearly does little good to define materiel which initially can execute tasks under conditions and to standards, but is nonsurvivable in the mission context.

A.3 Linking Levels of War Using MMF

It is important to understand that the full MMF diagram portrayed in **Figure 7** is only representative of military activities at a single level-of-war. Even for relatively small classes of actions, key military tasks take place at multiple levels of war nominally beginning at the National Command level, and then working down through the Strategic Theater, Operational, and, finally, Tactical Levels of war. **Figure A.3** illustrates the MMF levels of war linked vertically by both the mission build and the mission execution linkages on both the **OWNFOR** and **OPFOR** sides. The dotted-blue arrows represent a top-down decomposition through a **Level 4** primary task at one echelon linking to the **Level 7** directed mission for a subordinate unit at a lower echelon. Likewise, the solid red arrows illustrate the bottom-up linkage between mission effectiveness of a subordinate unit and the mission of the higher headquarters that relies on the success of its subordinates for its own overall mission effectiveness.

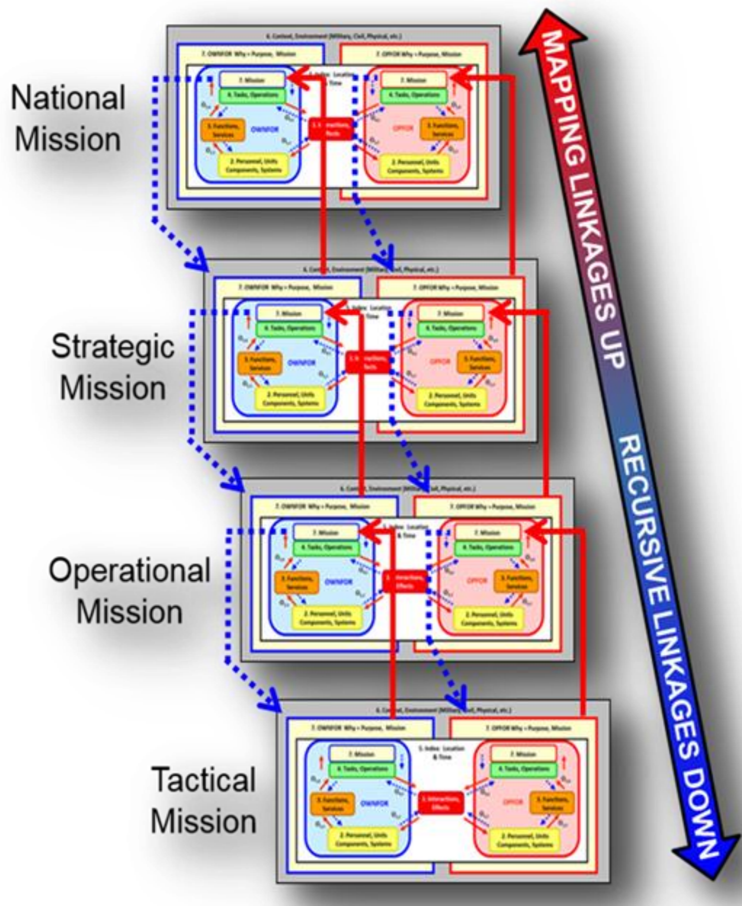

Figure A.3. The MMF connected vertically by levels-of-war. The single level-of-war shown in **Figure 7** is used recursively to provide logical structure for a top-down (dotted blue) decomposition processes and a bottom-up (solid red) assessment processes. Top-down linkages are established by recursion; bottom-up linkages are established by particular operators.

A.4 The MMF with Additional Forces

The MMF has been used in numerous studies involving two forces (**OWNFOR** and **OPFOR**). However the MMF has never been restricted to any specific number of forces on any particular side. One way of thinking about how the MMF is instantiated is to consider the modified diagram shown in **Figure A.4**.

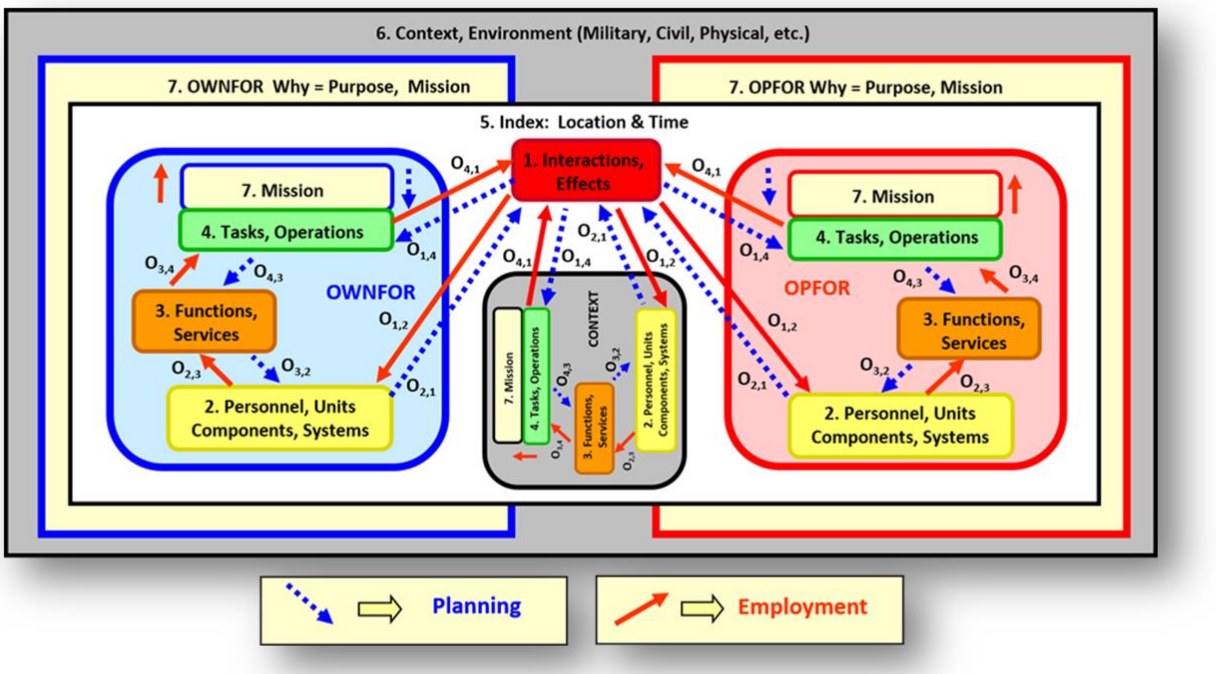

Figure A.4. The MMF modified for an array of cooperating/warring parties. The outer **Level 7** of Context has been omitted for clarity.

Here the standard MMF diagram has been modified with an additional force shown in the foreground as **Context**. The outer **Level 7** for **Context** has been left out for clarity. For an overall perspective, one can think of **Level 6**, **Context**, as initially containing all forces and equipment on all sides. From a logical process, the relevant **OWNFOR** are identified and elevated to populate **Level 2** on the left, and the same for the **OPFOR** to populated **Level 2** on the right. The rest of the levels and operators are as earlier. The grey **Context** force can be thought of as force distinct from either the **OWNFOR** or **OPFOR**, and oriented to playing some (semi-)independent role. A key point here is that all of the executing parties are both self- and cross-linked through the same shared **Interactions** and **Effects** level shown in red. This observation is critical to both the underpinning logic of the MMF process as well as its corresponding embodiment in executable code. One of the key takeaways is that although the MMF has multiple levels connected by both explicit and implicit operators, certain levels only "talk" to other levels, and the process of level instantiation must follow a specific causal order. Finally, **Figure A.5**, gives a second example of multi force instantiation of the MMF. Here there are four **OWNFOR** units illustrated. They could be any force groups at the same level-of-war, either from a single nation or a multi-national force.

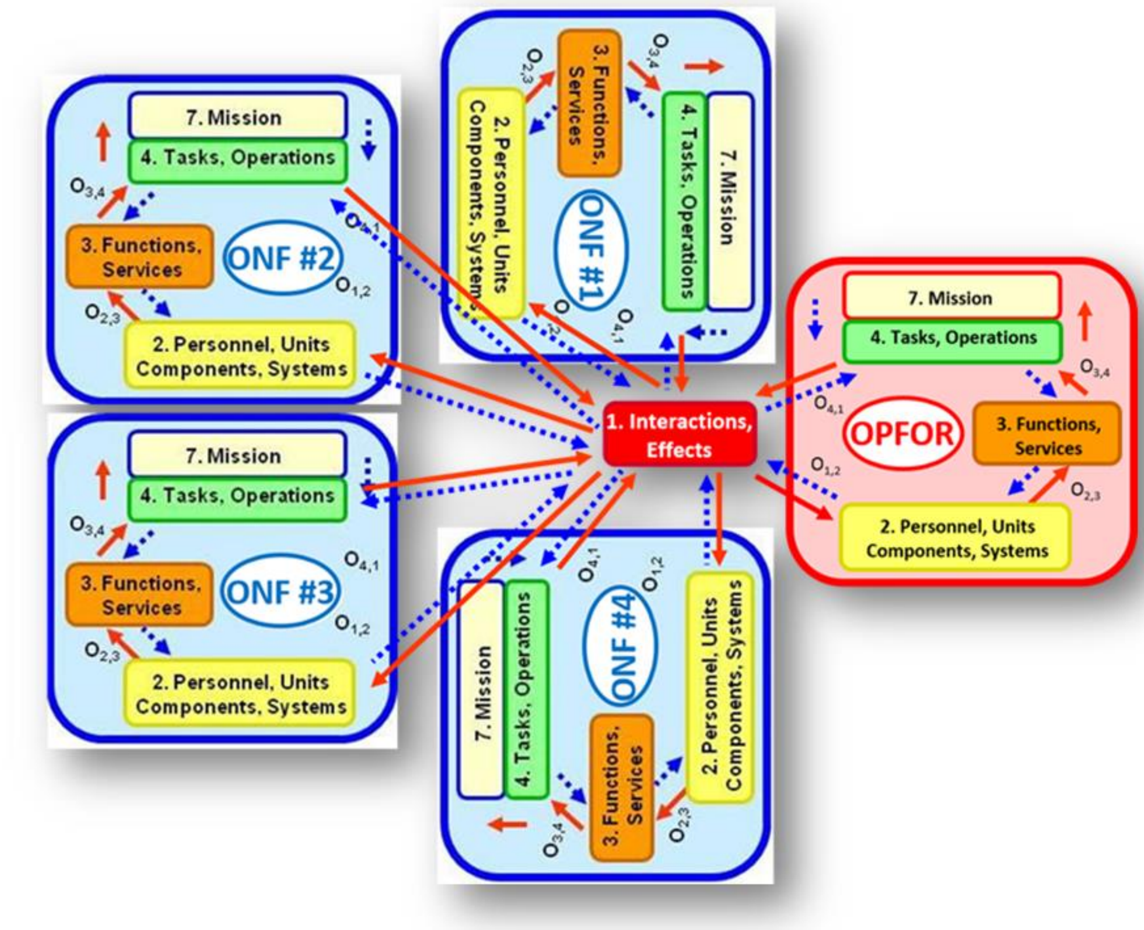

Figure A.5. The MMF modified for four **OWNFOR** (**ONF #1-4**) units. **Levels 5, 6,** and the outer **7s** have been omitted for clarity. Only a single **OPFOR** is shown.

APPENDIX B – CLASSES OF THE MMF ONTOLOGY

Currently, classes are defined for each of the 7 Levels of the MMF model. For each Level, two classes are defined: one corresponding to the Synthesis perspective, and another for Employment. The Level classes are defined as follows:

B.1 Level 1

Synthesis Class: Interaction
- Specifies how phenomena realized through execution of Tasks impact Forces.

Employment Class: Effect
- Packages that include multiple Interactions, organized by phenomena type and outcome.

B.2 Level 2

Synthesis Class: Components
- Specifications for types of particular assets. For instance, different varieties of tanks or artillery.

Employment Class: Forces
- Specific instances of Components (e.g., a tank corresponding to a component specification), packaged into a group for carrying out mission operations.

B.3 Level 3

Synthesis Class: Functions

- These express functional requirements needed to deliver specific Capabilities.

Employment Class: Capabilities

- These describe particular actions applicable toward achievement of mission operations.

B.4 Level 4

Synthesis Class: Task

- These are outcome-centric mission specifications.

Employment Class: Operation

- These describe steps involving usage of particular means to accomplish Tasks within a mission.

B.5 Level 5

Synthesis Class: Index

- These define particular locations within the context of lookup services, such as the Global Command and Control System (GCSS).

Employment Class: Location and Time

- A packaging of specific locations (as expressed by Indexes), grouped by time frames relevant to the mission.

B.6 Level 6

Synthesis Class: Context

- These express specific military, civil, and physical conditions under which missions are to be carried out.

Employment Class: Environment

- A packaging of Context factors, intended to frame conditions under which missions are carried out.

B.7 Level 7

Synthesis Class: Purpose

- Actions to be carried out in a mission, paired with supporting rationale.

Employment Class: Mission

- These describe sets of particular actions to be carried out without giving specifications on how they should be carried out.

APPENDIX C – PROPERTIES OF THE MMF ONTOLOGY

For the MMF Ontology, properties considered include Operators, linkages to support multiple levels of warfare, as well as linkages between Synthesis and Employment classes for the 7 Levels. Each of the 4 MMF Operators is encoded as an ontology property, designed to link MMF Levels in both Synthesis and Employment encodings. The notation applied toward naming these properties is as follows:

Op*<Mode><Subject>*to*<Object>*

Where the property <Mode> will either be for Synthesis (Syn) or Employment (Emp), and the <Subject> and <Object> will be numbers for appropriate MMF Levels. For example, the property *OpSyn1to2* will correspond to $\mathbf{O_{1,2}S}$ in the MMF notation from **Figure 7** (and [9]), while *OpEmp2to3* corresponds to $\mathbf{O_{2,3}E}$

Additionally, for each of the 7 Levels in the MMF model, classes are defined corresponding to both the Synthesis and employment perspectives. With each Level, a pair of properties is given: one that defines a relationship between the Synthesis and Employment classes, and another that expresses the inverse relationship. An overview is provided below for each of these property pairs:

C.1 Level 1: Interactions, Effects

Synthesis-to-Employment Property: Impacts (Subject: Interaction | Object: Effect)
Employment-to-Synthesis Property: Impacted By (Subject: Effect | Object: Interaction)

English Description: Individual Interactions between assets – organized by phenomena and time – will impact broader Effects on missions, while Effects will consist of one or more Interactions.

C.2 Level 2: Components, Forces

Synthesis-to-Employment Property: Part Of (Subject: Component | Object: Force)
Employment-to-Synthesis Property: Consists Of (Subject: Force | Object: Component)

English Description: A Component will describe one portion of a greater Force, while Forces will consist of multiple parts viewable as instances of Components.

C.3 Level 3: Functions, Capabilities

Synthesis-to-Employment Property: Required For (Subject: Function | Object: Capability)
Employment-to-Synthesis Property: Requires (Subject: Capability | Object: Function)

English Description: Functions will be required for particular capabilities, while capabilities will require specific functions.

C.4 Level 4: Tasks, Operations

Synthesis-to-Employment Property: Addressed By (Subject: Task | Object: Operation)
Employment-to-Synthesis Property: Addresses (Subject: Operation | Object: Task)

English Description: Tasks will be carried out using means allocations defined in Operations, while Operations aim to accomplish particular Tasks.

C.5 Level 5: Index, Location/Time

Synthesis-to-Employment Property: Referenced By (Subject: Index | Object: Location and Time)
Employment-to-Synthesis Property: References (Subject: Location and Time | Object: Index)

English Description: Location Indexes will be referenced by LocationAndTime packages, while LocationAndTime packages will reference specific Location Indexes.

C.6 Level 6: Context, Environment

Synthesis-to-Employment Property: Factor Of (Subject: Context | Object: Environment)
Employment-to-Synthesis Property: Has Factor (Subject: Environment | Object: Context)

English Description: Individual pieces of Context will be factors that define a broader Environment, while Environments will have one or more specific Context factors.

C.7 Level 7: Purpose, Mission

Synthesis-to-Employment Property: Objective Of (Subject: Purpose | Object: Mission)
Employment-to-Synthesis Property: Has Objective (Subject: Mission | Object: Purpose)

English Description: Purposes will be considered as objectives within the greater context of a Mission, while Missions will consist of one or more objectives expressible as Purposes.

C.8 Supporting Multiple Warfare Levels

In the MMF ontology, support for multiple warfare levels (as discussed in **Appendix A**) is provided through following properties:

- Corresponds To (Subject: Purpose/Mission | Object: Task/Operation)
- Helps Achieve (Subject: Task/Operation | Object: Purpose/Mission)

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