Army Materiel Systems Analysis Activity

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An Integrating Framework for Interdisciplinary Military Analyses

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An Integrating Framework for Interdisciplinary Military Analyses§

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ABSTRACT

In the 1950s, ballistic vulnerability/lethality (V/L) emerged from the study of terminal ballistics as a focus on target end state. By the early 1960s, wargames evolved in which key inputs, generated by the V/L community, were Probabilities of Kill (PK). Loss/Exchange Ratios (LERs) became a central measure of mission effectiveness. V/L and wargames are but two of many fields developed largely independently in what might be characterized as a bottom-up evolution.

There is now a significant need to develop and apply integrated analyses to determine required disciplines and tools. For example, the interest in Systems-of- Systems requires the application of multiple disciplines. Meeting these needs is not possible by simply combining a collection of "bottom-up" tools. There are serious realities that challenge the analytic community horizontally (factors at a single level of war) and vertically (factors connecting different levels war). These include:

- Analytic areas characterized by collections of metrics in which sharing or exclusion across areas is not understood,
- State changes to systems or components of systems (i.e., due to invoked damage or repair) are conflated with system performance and further conflated with system effectiveness, and
- Mission contexts are absent, making effectiveness estimates ambiguous at best.

As a community, we require a single, high-level abstraction that is logically linked to lower dimensions. We suggest that the doctrinal planning and decision-making discipline, the Military Decision-Making Process (MDMP), can serve as just such an overarching abstraction. When properly applied, both necessary and sufficient metrics can be identified and shared, and exclusionary uses of the same metric in different subspaces illuminated. For the past decade, efforts have been made to provide a formal structure for the MDMP by defining mathematical levels, operators, semantic usage, proper linkages, and order of data instantiation. We call this the Missions & Means Framework (MMF) and suggest that it can serve as an analytic metaphor for the MDMP. Finally, we assert that the MMF can be applied as the overarching framework needed to identify requirements with significantly increased clarity as well as helping to structure the application of more narrowly focused analytic tools and techniques across the Department of Defense (DoD).

INTRODUCTION

After World War II, the foundation of ballistic vulnerability/ lethality (V/L) study emerged as an extension of terminal ballistics. The focus of V/L study was the platform (e.g., tank, aircraft, human) end state rather than simply warhead-armor interaction. Various metrics were developed by the V/L community typically under a label of "Probability of Kill," or "PK." By the early 1960s, wargames relying critically on key PK inputs generated by the V/L community evolved. And Loss/Exchange Ratios (LERs), a measure of enemy-to-friendly platforms destroyed, became a central measure of mission effectiveness.

The V/L analyses and wargames are but two of many fields developed largely independently in what might be characterized as a bottom-up evolution. Over the intervening decades, many disciplines have emerged. In addition to ballistic V/L, examples include:

- Mission requirements specification,
- Basic and applied research,
- Material research,
- Analysis of human dimension,
- Cost estimation,
- Investigation of effectiveness,
- Logistics,
- Battlefield repair,
- Operations research/systems analysis,
- Systems-of-Systems tradeoffs,
- Developmental & operational testing,
- .

Clearly these categories represent a fraction of the important foci across the DoD. But what we can observe is that these disciplines, in the main, have arisen independent of one another, mostly in bottom-up activities. There certainly has been no overarching structure or framework to which these areas had to adhere.

Is this really a problem? In the next section, we describe important challenges that confront the DoD community because key interdisciplinary metaphors should be strengthened.

PROBLEM DEFINITION

It is widely recognized that military systems today are more complex than ever before; and at the same time, military operations present social and political challenges far beyond characterization of kinetic effects. As a result, more than ever across the DoD there is a significant need to develop and apply integrated analyses to determine required disciplines and tools. Meeting these needs is not possible by simply combining a collection of "bottom-up" analyses. The issue here is not a problem with computer coding or software interoperability. There are serious logical disconnects and incompatibilities in the underpinning logic that challenge the analytic community horizontally across a single level of war. And the problem exits vertically as well when connecting multiple levels of war.

Some of the more notable byproducts of these practices are:

- Acquisition programs are typically pursued <u>without detailed explanation</u> of the value added and associated risk assessments in <u>operational context</u>, relative to higher and lower-level missions.
- Effectiveness analyses (e.g., requirements, wargames, test, evaluation) are therefore not structured in a way that clearly relates <u>system requirements</u> to <u>operational necessity</u> using approved doctrinal terms.
- Where mission context is absent, attempting effectiveness estimates is uncertain at best.
- Analytic exercises in which (sequentially) a] state changes to systems or components of systems (due to invoked damage or repair) are b] conflated with system performance and c] further conflated with system effectiveness.
- An array of analytic areas characterized by collections of metrics in which commonality or exclusion across disciplines is not known.
- Because standard language is often absent, there is imperfect communication of ideas and even metrics across and even within communities of practice.

A significant reason for these problems is the absence of formal mission descriptions. The results are often:

- Material and soldier performance metrics are evaluated with <u>incomplete knowledge</u> of risk *versus* reward trade-offs.
- Acquisition activities proceed without standard, shareable performance and effectiveness metrics.

Specific analytic and test activities are prosecuted in isolation without the ability to <u>integrate</u> them holistically.

- System-of-System analyses proceed in the absence of requisite operational "team" context obtainable only from formal operational specification. But operational context is critical to assessing the proper "blends" of multiple disciplines.

Before confronting these issues in the large, we examine a comparatively contained, well-known class of ballistic warhead/target events at a tactical level of war.

A TACTICAL WARFARE EVENT

To illustrate this problem set, we review an actual analytic challenge that became paramount to the Army in the 1980s.

Up to this time, program requirements specified total protection (i.e., generally admitting no armor penetration) for rounds up to a certain level of lethality. Testing generally focused on rounds requiring 100% protection. Overmatching attacks were simply conceded events since penetration could not be avoided. And generally for overmatching munitions, no tests were performed, particularly on full-up platforms, particularly ones fully loaded with ammunition and fuel. In the early 1980s, as a number of major Army programs was heading into Low-Rate Initial Production (LRIP), multiple voices raised valid concerns having to do with the battlefield survivability vis- à-vis overmatches. Clearly, armor overmatch can lead to a full range of outcomes from trivial internal damage to catastrophic reaction! It became appreciated that delineating the possibility and likelihood of particular outcomes could provide important links to the degradation or total loss of system performance, including most importantly the causes of loss or injury to crew.

Beginning with the establishment of the *Joint Live-Fire Test Charter* (Linder, 1984) and later reinforced with the *National Defense Authorization Act for FY 1987* (Live Fire Testing, 1986), "realistic" vulnerability testing utterly changed the Test and Evaluation (T&E) landscape, bringing extreme new challenges in test methodology, V/L modeling methods, and cost containment.

A key component of the live-fire regulations was that computer simulations were to be run prior to test execution to compare the test outcome with model predictions. The first program to follow this practice was that of the Bradley Fighting Vehicle. The most applicable vulnerability model at that time was used to support the program (Bradley Survivability Enhancement Program, 1985). There were many critics of the program, but the issue of relevance here is the use of the extant V/L models to provide shot predictions for the actual field tests. The V/L model support for the Bradley program was heavily criticized as being unreliable (General Accounting Office, 1987). The Abrams Live-Fire Program followed quickly, with the same requirement to provide pre-shot predictions for more than 50 munition/target combinations. At the outset of the modeling preparations for the Abrams program, workers examined the problems involved in simulating actual live-fire shots, and then developed some fairly radical strategies for live-fire prediction. Readers interested in the details can peruse Deitz and Ozolins (1989) and Deitz and Starks (1997).

For our purposes now, however, the problems encountered in the 1980s with V/L analysis are illustrated metaphorically by **Figure 1**. Here a threat/target interaction is characterized by essentially a single black-box model in which the round/hit point is input to the model and a single PK comes out of the computer. In this approach a lumped-parameter model is invoked in which internal details and intermediate results are hidden or unknown. A key attendant issue then, and even to this day, is the manner of both the generation and interpretation of the PKs in the simulation. Again, the reader is directed to Deitz and Starks (1997) for a discussion of these issues; however, we simply observe here that it is highly unusual for the outcome of an event (outside the field of V/L) to be characterized by a probability <u>after</u> the event is played out!

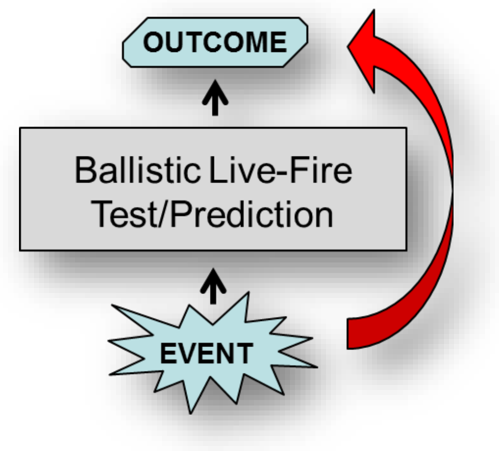

Figure 1. A simple, lumped-parameter model abstraction. An early vulnerability model can be thought of as having an **EVENT** initiation with an **OUTCOME**, but no intermediate results.

During the run-up to the Abrams Live Fire tests, Army modelers attempted to refine the "black box" illustrated in **Figure 1** by subdividing it into a sequence of three distinct mathematical spaces or levels, (forward time) connected by operators (shown as red arrows. A new V/L model called SQuASH was developed, and it was designed to calculate first damage, then map the damage to platform capability, and finally map capability to Effectiveness (or Utility). The basic outline is shown in **Figure 2.** The original structure attempting to formalize this level of thinking was called the V/L Taxonomy (Deitz, 1996). (Note: The numbering schema for the L**evels 1-7** is discussed in Deitz et al., 2009, as well as later in this text with **Figure 5**, etc.)

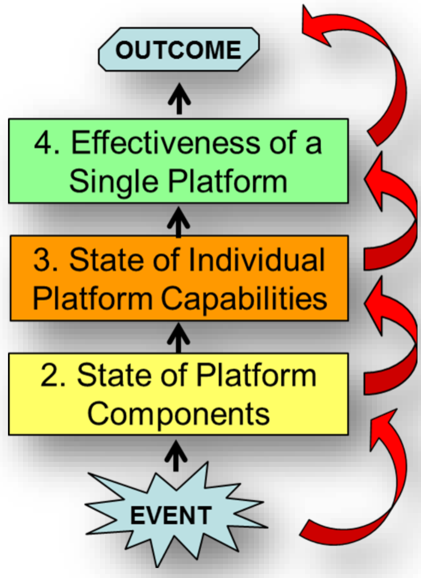

Figure 2. A metaphor used for the Abrams Live Fire modeling effort. An **EVENT** results in component damage at **Level 2**. Damage at **Level 2** changes platform capability at **Level 3**. Reduced capability leads to a lowering of Effectiveness at **Level 4**, the **OUTCOME** of the complete process.

The decomposition of the V/L process leading to the structure of the V/L Taxonomy set the stage for clarifying the associated test/model metrics and increasing the likelihood of model validation. However, a number of key hindrances remained:

- As noted elsewhere, the PK results in the V/L models came from a concatenation of **Level 3** and **Level 4** metrics such that, due to their intrinsic subjectivity, the results could not actually be compared with test results from the field.
- The inability to generate **Level 4** metrics other than PKs hindered the application of V/L model results beyond wargames to a wider set of analytic problems.
- Other than in a few special studies (e.g., Abell et al., 1990), neither in the standard practice of V/L modeling nor in field testing have significant efforts been directed to the estimated or measured mappings between component state space and platform performance.

Nevertheless, the pursuit of this more detailed structure made possible later refinements to an advanced version of the MUVES SQuASH model (Baker et al., 1998), which greatly enhanced the ability to compare intermediate and final model outputs to the original Bradley live-fire field test results. A few observations:

- There are many interaction mechanisms beyond ballistic. With the three-level decomposition shown in **Figure 2**, it is possible to develop component state change algorithms reflecting other damage classes (e.g., high-power microwave and laser damage, and physics of failure); and on the positive side, there can be algorithms describing battle-damage repair, resupply, or sleep for fatigued warfighters.

- The health of the components at **Level 2** doesn't depend on the origin of their state change. Likewise, once an adequate utility is represented at **Level 4**, the effect of many different phenomenologies can be assessed by the two latter mappings.
- Finally, this structure of **Figure 2** shows how to integrate combinations of many component change mechanisms. As they arise over a mission, the running states of component health can be remapped to platform capability and then to mission effectiveness.

Even with this comparatively simple example at a single level of war, we can see that the decomposition of a complex event into its constituent pieces can add clarity and useful insight into bringing model intermediate and final results into consonance with field-testable metrics. Nevertheless, the structure illustrated in **Figure 2** falls far short of a framework capable of dealing with the broader issues of warfighting. To conceptualize a more general framework, we turn to the world of the professional warfighter.

A final point. As a matter of routine, when high-resolution V/L models (i.e., those that characterize internal platform components in detail) are exercised, they are typically capable of providing intermediate levels of capability and (therefore) intermediate effectiveness too. However, typical practice is to post-process such metrics into Bernoulli PKs. By this means of reporting, any kind of ballistic interaction with a platform can only result in an <u>all or nothing outcome</u>. We suggest that these (binary) outcome metrics cannot provide the resolution required in contemporary test and analysis venues. More on this issue later.

<u>HOW ARE MISSIONS PROSECUTED?</u>

We now turn to the professional warfighter (or operator) to see how they develop, prosecute, and assess virtually all missions across the Range of Military Operations (see Joint Publication, 2011). For many years, warfighters have used the Military Decision-Making Process (MDMP) (see, for example, Marr, 2001) as the underlying framework for planning, structuring, organizing, and executing all manner of missions, whether "kinetic" or not. **Figure 3** illustrates the MDMP developed to analyze a Military Operation in Urban Terrain (MOUT) mission (Harris et al., 2000). It consists of sequences of tasks hierarchically structured by level of war, ultimately from the National Command Level down to the Tactical Atomic. The laydown of tasks can be compared to the construct of PERT or Gantt charts typically used in a variety of applications for prosecuting complex projects.

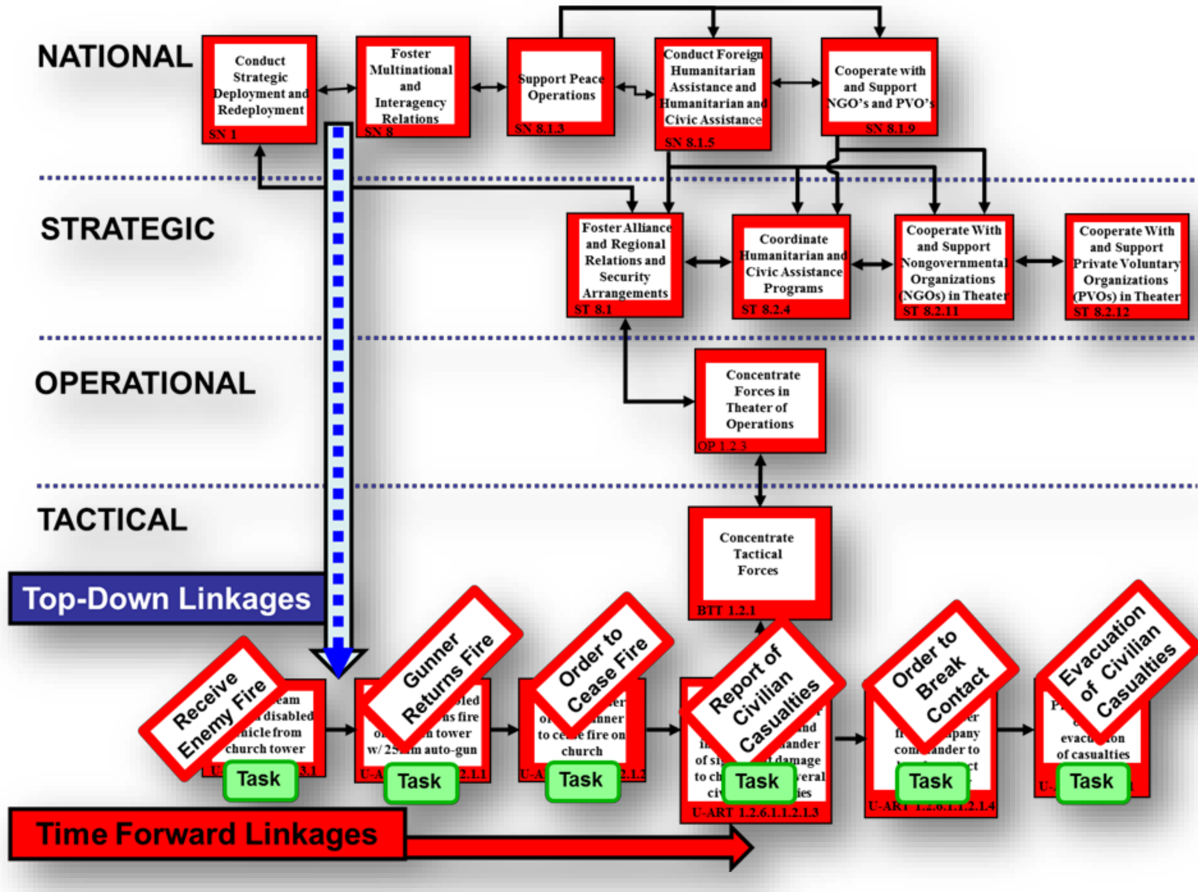

Figure 3. Part of a MOUT mission layout by level of war. In general, the higher-level tasks are defined and portions passed to lower levels for either execution and/or further decomposition. The dashed blue line represents the top-down inferred relationships. The red arrow indicates time forward.

Further:

- The MDMP is all about mission planning and task execution, monitoring results and assessment of progress against mission objectives. Tasks are ubiquitous!
- A key issue of semantics is solved since the establishment of a Universal Joint Task List (UJTL) (Chairman of the Joint Chiefs of Staff, 2012) to specify and describe tasks (with Conditions and Standards) from the National Command level down through the Operational level of exercise. Each Service has its own lists that describe its Tasks (with Conditions and Standards) from the Operational to the Tactical Atomic (lowest fighting levels). The tasks for the Army are defined by the Army Universal Task List (Headquarters, Department of the Army, 2012).
- When informed by key reference missions (including Joint and Service concepts), the MDMP should serve as the single integrating framework for the Defense community.

- Materiel Requirements should derive from analysis of requirements for successful task execution, under appropriate conditions and standards.
- 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 illuminated. (See Appendix A for a discussion of mappings.)

We suggest that doctrinal planning and decision-making processes such as the MDMP, when used to define and instantiate a mission, can serve as just such a highest- level defining state space. When properly applied, both necessary and sufficient metrics can be identified and shared and exclusionary uses of the same metric in different subspaces illuminated. 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 shown in **Figure 4** 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 . . . " (Chairman of the Joint Chiefs of Staff, 2012).

THE MDMP AS A FORMAL STRUCTURE

The first issue that might arise is why does the Military Decision-Making Process need a formal structure? The answer lies in the MDMP's target audience─military planners and operators. It is a process designed to guide mission analysis, planning, and assessment of ongoing operations, and it assumes an advanced level of familiarity with military doctrine and doctrinal terms and graphics. The MDMP focuses on development and production of outputs (briefing charts, plans and orders, etc.) that are meant to convey the results of the process to military decision-makers, staffs, and executing organizations. These outputs are normally generated in the form of flat file text and graphics using the doctrinal terms and graphics familiar to the target audience. For the vast majority of the

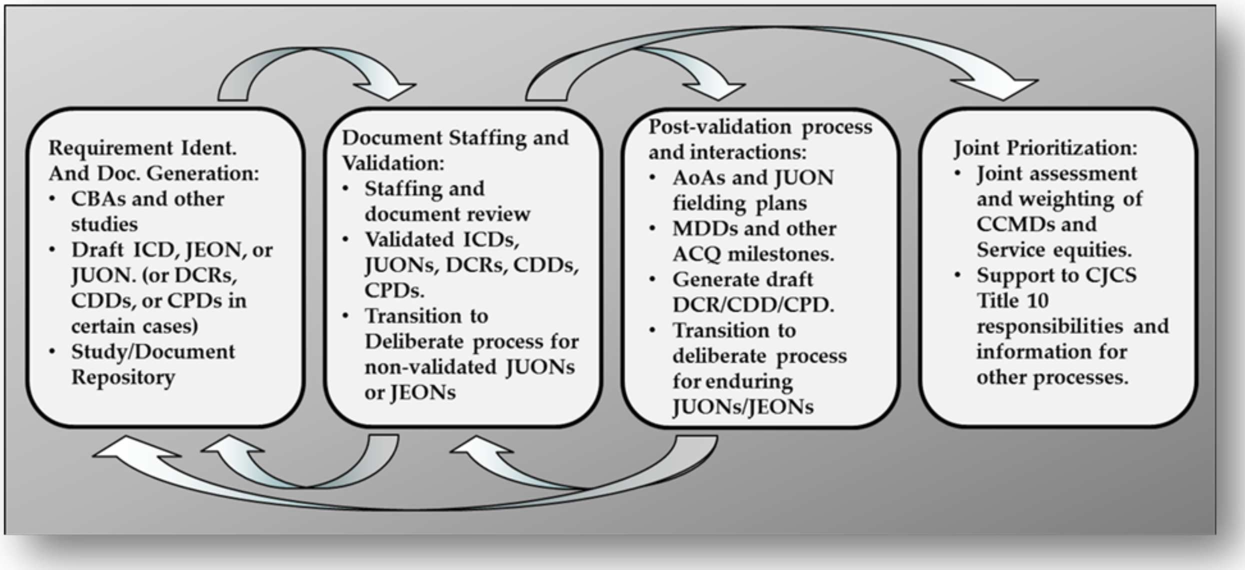

Figure 4. The Joint Capabilities Integration Development System (JCIDS) process.

civilian and contractor workforce supporting the operating forces can be difficult to understand and even more difficult to apply. Because these products are outputs of the MDMP process, there is usually little- to-no documentation of the detailed thinking, discussions, and subprocesses that lead to the final output. And when such documentation does exist, it is conveyed using the same community-specific language not commonly understood in the larger DoD community. With so much at stake, we suggest:

- 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 the application 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.

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 V/L Taxonomy was originally focused on a specific kind of task execution and embodied the notion of physical state space (i.e., the platform or person), the related capability of the platform, and the "utility" of the platform. Upon the emergence of the semantics established by the UJTL and Service Task Lists, it seemed that the illusive issue of effectiveness should turn on the ability to execute tasks. Finally, it was clear that the proper occupant of **Level 4** (per **Figure 2**) should be tasks, not probabilities.

THE MISSIONS & MEANS FRAMEWORK (MMF)

As noted earlier, the V/L Taxonomy, although providing useful insights to single platform encounters, fell far short of a complete description of warfare. To remedy these limitations, the MMF (Sheehan et al., 2003) evolved from an integration of the V/L Taxonomy, the Task Lists construct, and additional requisite context information necessary to define, execute, and monitor warfare. These efforts resulted effectively in a structure that can serve as an analytic surrogate for MDMP. Further description can be found in Appendix E of the monograph by Deitz et al. (2009).

MMF has also been discussed elsewhere (e.g., Sheehan et al., 2003; Deitz et al., 2009, Appendix E; Ward et al., 2012), so the description here will be brief. Depicted in **Figure 5**, the 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**). The data to be stored and organized using these three levels include the results of front-end analysis processes for missions received or derived (e.g., mission analysis and intelligence preparation of the mission space). This information is normally published/found in paragraphs 1 (Situation) and 2 (Mission) of the Operations Plan (OPLAN) and in supporting annexes. Once a mission has been received/derived and analyzed, the MDMP is 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 5**.

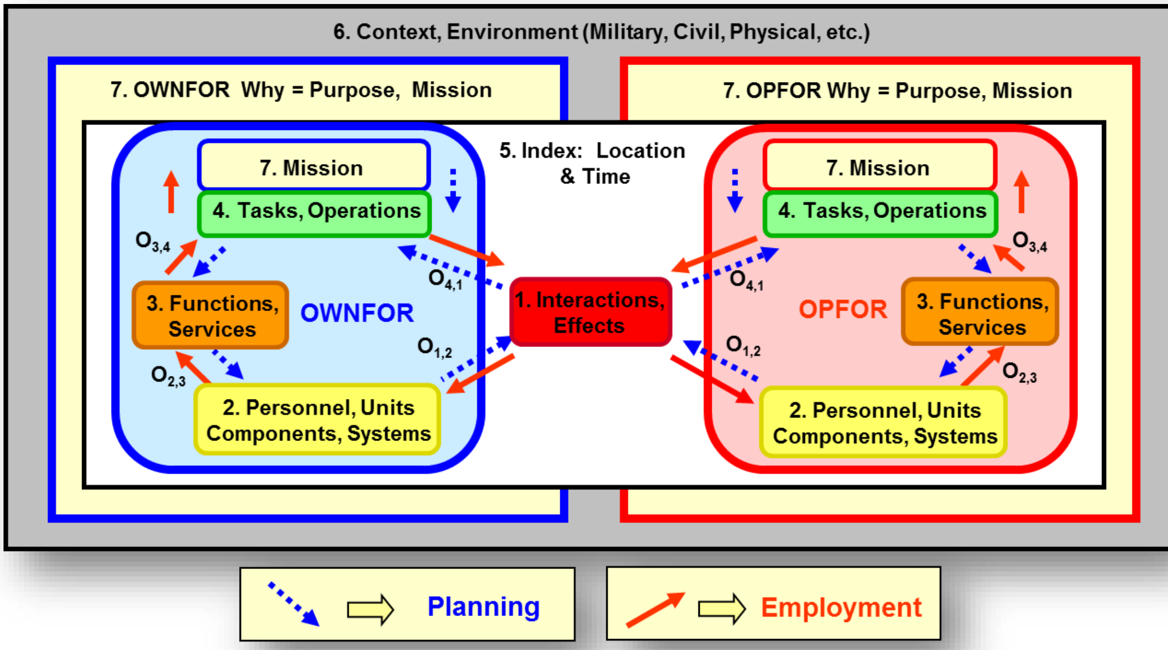

Figure 5. The Missions & Means Framework. The MMF is characterized by eleven fundamental elements: seven levels and four operators.

Note that **Levels 5** and **6** represent a portion of the mission context that is shared by all entities as represented by the **OWNFOR** (Own Forces) and **OPFOR** (Opposition Forces) 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. 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). Note also that **Level 1**, in the center of the MMF is a shared space, representing the interactions and resulting effects that task execution by any side can have on itself, other sides, and environmental variables. 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.

TASK PROSECUTION

We now examine the explicit task-processing processes that are represented by the front-most layer of the **Figure 5**. For simplicity, **Figure 6** shows the front layer of task execution entities for the **OWNFOR**. **Level 4**, shown in green, represents a particular task. Moving clockwise (time forward), the **$O_{4,1}$ 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 phenomenologies. The **$O_{4,1}$ Operator** when called repeatedly acts as 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 **$O_{1,2}$ Operator** causes changes to the people/materiel represented at **Level 2**. Interactions can either be "negative" (causing damage) or "positive" (fixing damage).

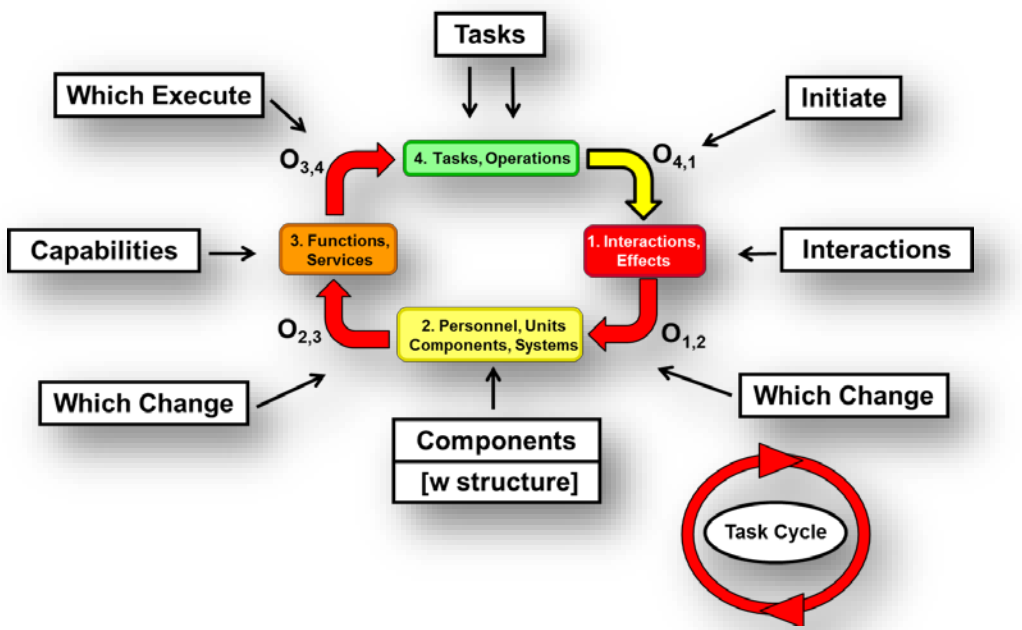

Figure 6. An illustration of a Task Cycle. A task at **Level 4** initiates an interaction at **Level 1**. The **$O_{1,2}$ Operator** changes the state of the components at **Level 2**. A new capability is computed at **Level 3** and then finally compared with the capability required for the next task 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° revolution) from initiation to final capability/task comparison via the **$O_{3,4}$ Operator** might represent a single Developmental Test.

The **$O_{2,3}$ Operator** takes the current state of **Level 2** and maps it to its current capability. The geometry representing complete platforms (both external armor and interior components) has been characterized by BRL-CAD® for many years (see Anderson and Edwards, 2004, and BRL-CAD, 2013). Key to the analysis of V/L effects is a full representation of component geometry to include just which warfare functions by platform system. The characterization of key functions (e.g., firepower, mobility, communication, etc.) are often represented by fault trees. Such trees underwrite the extent to which components are critically vulnerable or have redundant support. When these trees are properly structured, the damage state of the component systems can be used to estimate the level of specific performance in a <u>continuum</u> from fully functional to nonfunctional.

After a new capability at **Level 3** is estimated, it is then compared to the **Level 4** by the **$O_{3,4}$ 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 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, for example, 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.

We make some observations concerning the levels of the Task Cycle. As illustrated in **Figure 7**, we note that the components and capabilities are predominantly objective. Material elements are inherently physical and measureable; 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. This top-down process is

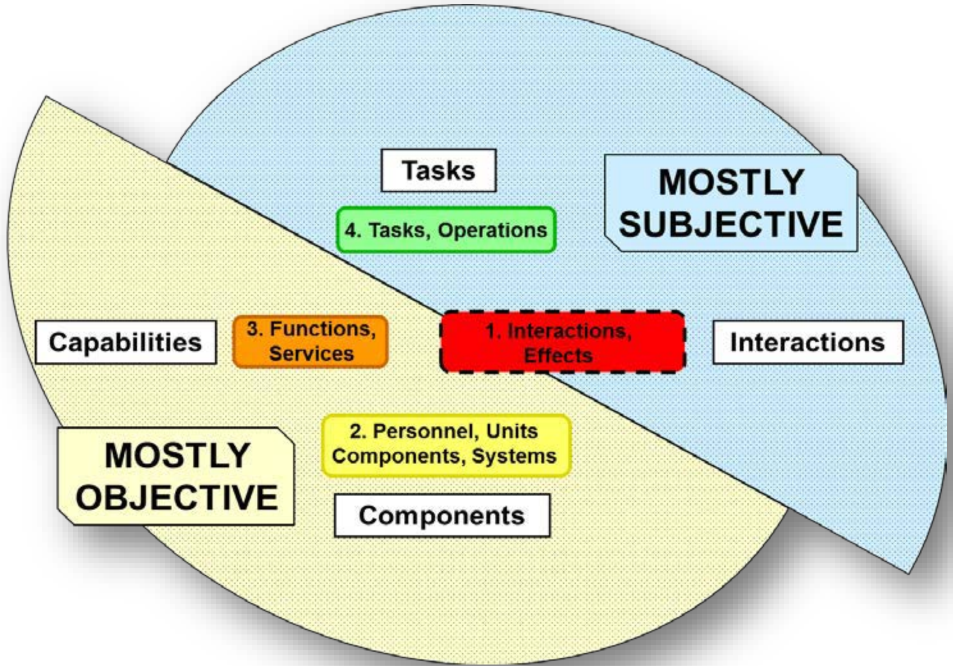

Figure 7. Objective/Subjective partitioning of the MMF. Within each force, the four front levels of MMF are categorized as totheir objective vice subjective nature. Material components/ capabilities are inherently objective; cognitive components, not! Tasks are inherently subjective while **Interactions** are a split depending on whether they are an operator (subjective, top-down) choice or the result of a physical stimulus (under time- forward exercise).

represented by the dotted blue links shown in **Figure 5**. That is why we show **Level 1**, **Interactions**, spanning both categories.

INTERACTIONS BETWEEN OPPOSING FORCES

The MMF diagram of **Figure 5** shows two opposing forces. We want to illustrate the four basic variants of task execution. **Figure 8** shows the two forces with the time- forward operators. **Level 1**, **Interactions**, is shown outside of the force descriptors since they are "owned" by no one, but defined by the laws of nature.

When tasks are initiated by a force, they can be of two forms. Starting from the left in **Figure 9**, the **OWNFOR** can be self-directed, initiate a task on itself, operating a vehicle is such an example as it causes depletion of fuel. The second type 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**

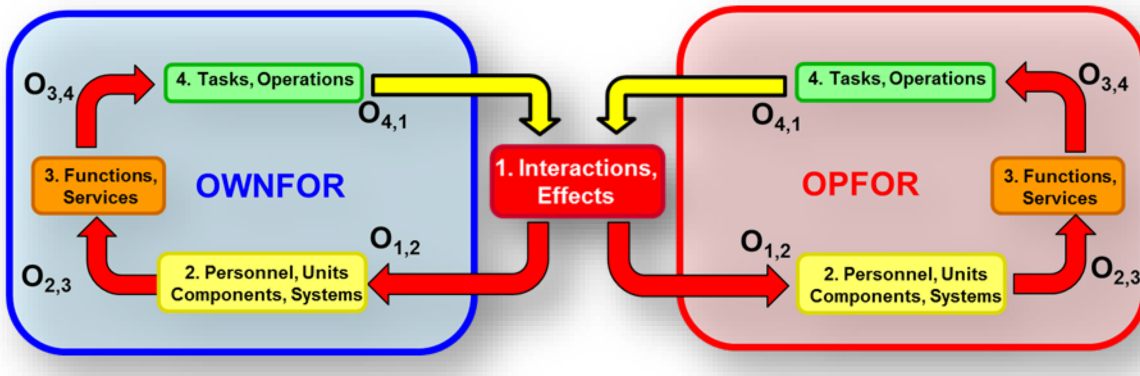

Figure 8. The operators of the MMF. The opposing forces of MMF are shown with the time-forward operators. Note the **OWNFOR** (time-forward) operators move clockwise; the **OPFOR** move counterclockwise.

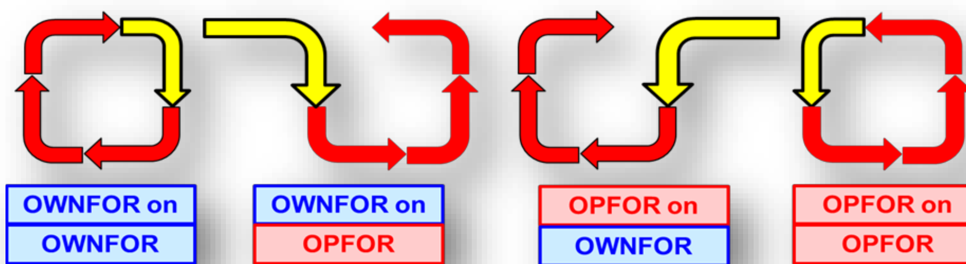

Figure 9. Two kinds of tasks, the MMF self-directed (the two outer diagrams) and the two outward-directed (the two inner diagrams).

materiel. The third and fourth elements 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. 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.

IMPORTANT TAKEAWAYS

It is important to note that the four levels represented in the MMF, **Figure 6**, are formed by classes of metrics that are the largest that they can be while still remaining homogeneous as a class. 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. 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.

In **Figure 1** we illustrated a V/L estimation as a lumped-parameter process. The standard outcome used widely in the community is a PK. As stated previously, the interpretation of PKs is ambiguous at best and certainly not relatable to elements of a task lists. Further, in keeping with the lumped parameter process, the preponderance of V/L estimates do not provide a **Level 2** damage vector (list of working/nonworking components). The **Level 2** metrics are not mapped to a **Level 3** capability to be related to a task to be executed at **Level 4**. The output is the PK, which is used as a Bernoulli draw in a wargame. When multiple hits are received on a target, a number of PK events are computed individually, assumed to be actual probabilities, and assumed to be independent, and then combined by the Survivor Sum rule (see Endnote, p. 36).

Returning to **Figure 6**, we observe once again that interactions change the material/ people at **Level 2**. If a sequence of events occurs, then the state of **Level 2** must evolve by steps. To state it a different way, the aggregation of effects occurs at **Level 2**. As **Level 2** evolves over time, the capability at **Level 3** and effectiveness at **Level 4** follow. What happens in areas of analysis is that individual interactions are mapped through **Level 2** to **Level 3** and more often to **Level 4**. The aggregation/integration of multiple interactions are incorrectly estimated by combining multiple performance **(Level 3)** or effectiveness **(Level 4)** metrics. This is clearly wrong, but hard to perceive absent a logical framework. Compounding this problem is the fact that virtually all wargames treat platforms as black boxes with assigned properties. They are not represented with working components that can break or be fixed. Hence for these simulations, there are no dynamic **Levels 2, 3**, and **4** and, therefore, no way to develop combined effects properly!

Further, because in the standard wargame PKs are used as Bernoulli draws, outcomes are either 0 or 1. There are no intermediate values. Platform performance characterized by binary states therefore provides an inadequate measure of task performance.
To review some key points:

- The inability to define the "PK" metrics objectively/ quantitatively as well as lack of objective intermediate damage and performance metrics contributed greatly to the Live Fire Program issues in the 1980s.
- Lumped parameter metrics in general are problematic with respect to both interpretation and integration with other parameters!
- Absent context and intermediate results, the contribution of each of the three components (physical state change, capability change, and change in mission challenge) cannot be apportioned to create data extensibility.
- PKs are actually binary measures. As such, they represent the average of many elements of an ensemble. Comparison of single members of the ensemble with the average is not appropriate.
- With such characteristics, PKs are fundamentally useless for providing insights to task performance.
- However, when fighting components are abstracted at the level of resolution portrayed in **Figure 6**, an extensible construct is formed which is capable of describing and integrating a large number of phenomena (see **Figure 10**)

The issue of test/model duality to estimate performance for comparison with task requirements is key to understanding the prosecution of the MDMP. We've emphasized the importance of estimating a continuum of performance values for key platform capabilities. In APPENDIX B, we provide the logic for determining mission readiness.

MEASURING AND ESTIMATING COSTS

Having introduced the four front layers of MMF, **Levels 1-4**, as well as the suggestion that they relate to natural language word classes, it is opportune to discuss the issue of costing warfighting. Clearly, the monetary resourcing of DoD initiatives is among the most important considerations. Any analytic framework unable to support cost methodology would hardly be useful.

There are two obvious foci in MMF that provide links to measure and estimate costs. The first characterizes the cost of materiel at **Level 2**. Such estimates, for example, would reflect the purchase costs for weapons. The second focus is found at **Level 4**, Tasks. From this perspective, the goal is to fix the cost of actions or activities. In fact, this approach matches the well-established practice of Activity-Based Costing (ABC) found throughout financial and accounting worlds. Those interested methodologies to identify, measure, and categorize the various costs in defense analysis are directed to Nelson (2006) and Deitz (2009, p. 224).

A LEGO COLLECTION OF MISSION PERFORMANCE ELEMENTS

In the prior sections, we have reviewed all of the pieces needed to construct an MDMP analog. The seven levels (see **Figure 5**) provide needed context. The task definition and execution pieces are shown in **Figure 10**. With the Universal and Service task lists, the semantics of **Level 4** are well established. At **Level 2**, the military hierarchical naming conventions for people and materiel have been well practiced for a few thousand years! The semantics of **Level 3** need to follow from the appropriate tasks defined in the official task lists. That way, when a mapping is made from the state of components to the corresponding capability, it will be immediately obvious whether or not it meets or exceeds the **Level 4** task requirement. Probably the elements of **Level 1**

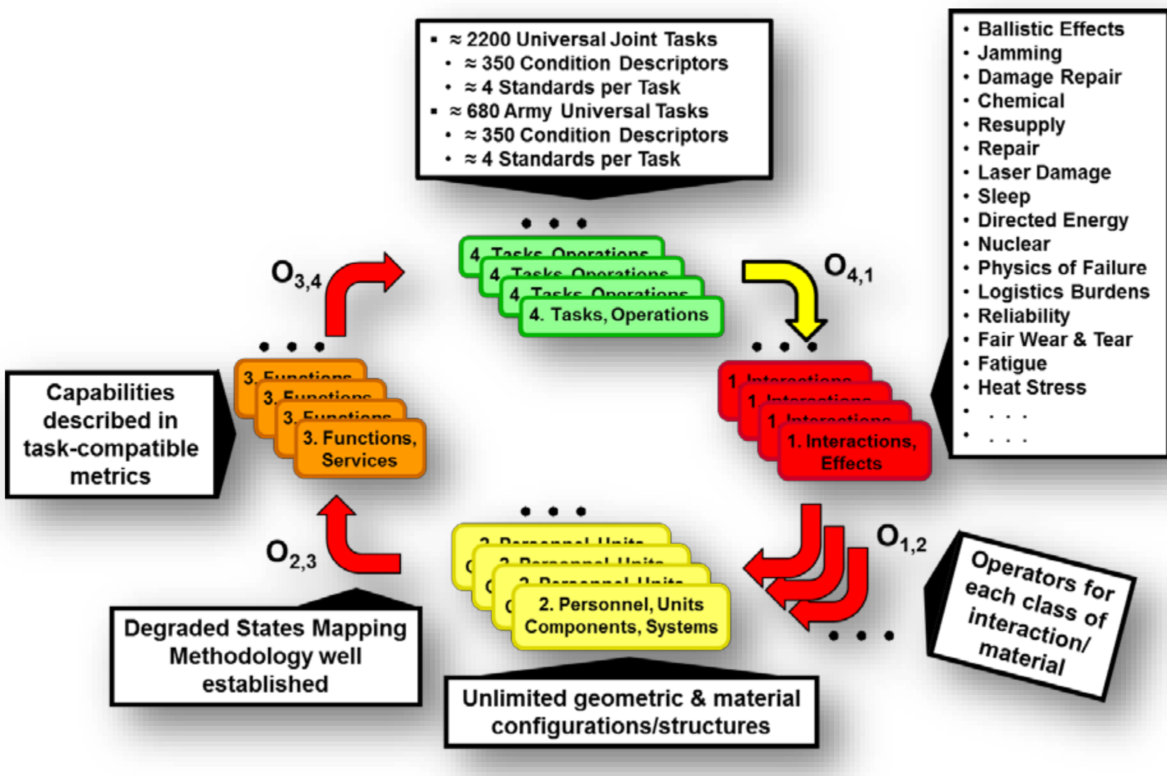

Figure 10. The key elements of task execution. The four classes of levels and the four classes of operators and be thought of as logical "lego" pieces. Each element can be developed and tested individually and then combined in endless combinations to define specific Task Cycles.

have received the least standardization. Nevertheless, the V/L community has much experience in constructing a range of ballistic operators to cover a large collection of warhead/target interactions. And there are many experts in a diverse set of disciplines capable of quantifying their respective phenomenologies.

THE TEST/MODEL DUALITY OF MMF

Previously, the MDMP has been described as the accepted warfighting paradigm in which sequences of tasks at connected levels of war are executing by assigned entities (people/ platforms). Supporting the MDMP, the MMF structures not only how task sequences are formulated, but what entities are assigned to the execution of those tasks. The paradigm necessarily recognizes that physical entities change over time due to task execution from both internally generated and external factors as well.

We posit that, to be of use, the MMF structure must be adequate not only to the theoretical (modeling, calculating) side of enquiry but to testing (observation, measuring) as well. In fact for model (or even test) validation to occur, the theoretical and test abstractions must be fully shared. This property, the sharing of a common abstraction between the test and model worlds has not been widely practiced in much of the test and analytic worlds. The sharing of the MMF structure should be one approach to minimizing that problem.

APPENDIX C discusses the parity issue in further detail.

CONSTRUCTING A DEVELOPMENTAL TEST

Now with our various lego pieces in hand, we can construct a variety of Task Cycles with breadth and depth tailored to questions at hand. They can be responsive to tasks defined at **Level 4**, with a frequency defined by the **$O_{4,1}$ Operator**, and linked to a large class of chosen effects listed on the far right of **Figure 10**. The class of effect calls the appropriate **$O_{1,2}$ Operator**, which causes changes to occur at **Level 2**. Next, the concomitant capability(ies) change at **Level 3** via the **$O_{2,3}$ Operator**, and finally a comparison is made with **Level 4** to gauge the required capability for the next cycle.

A single Task Cycle (as in **Figure 6**) might represent one exercise of a Developmental Test (DT). A DT planning process might consist of reviewing each of the four levels and each of the four operators to establish the degree to which each is known for the context variables likely to be encountered during testing. A system under development is characterized by many possible task responses. The Task Cycle (**Figure 6**) can be used to first list the set of system responses appropriate for performance and testing purposes. The particular elements of the Task Cycle can be reviewed with respect to responses both from an M&S as well as a testing perspective.

CONSTRUCTING AN OPERATIONAL TEST

As we've seen, mission threads are composed of a sequence of Task Cycles as illustrated in **Figure 3.** The task sequence (or thread), illustrated in **Figure 11**, can be used to emulate an Operational Test (OT). The disciplines listed around the thread point to the variety of investigators who can be informed concerning their particular area of expertise and responsibility.

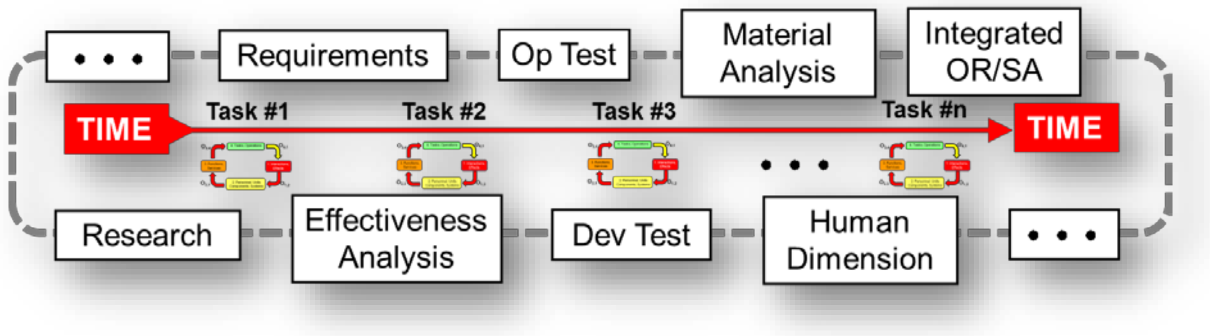

Figure 11. Illustrating a mission thread. A sequence of tasks, each with its attendant Task Cycle. The disciplines surrounding the thread points to the many areas of DoD research, engineering, costing, and analysis that can be informed by such an integrated process.

Some classes of levels/operators might be of interest only narrowly. But that is likely to be the exception; much in this construct is shared. All can use the characterization of mission effectiveness based on a shared mission build. In fact, everyone should be able to share in the levels and operators from **Level 2** around to **Level 4**. One would expect diversity in the behavior of the **$O_{4,1}$ Operator**, which establishes what modeling circles call the Time-Ordered Event List (TOEL); and also in the **Level 1** interactions and the **Level 1** and **$O_{1,2}$ Operator**. But if the community were to work in this uniform paradigm, everyone could share the same effectiveness objectives and have the means as well of interleaving platform interactions, making possible truly integrated performance estimates!

A final element in establishing standards, commonality, and exclusivity across the DoD community is that this structure can greatly aid the process. In recent years, there have been many bottom-up exercises to establish common metrics and naming conventions. But bottom-up processes are ambiguous both in establishing false shared metrics (because the names might be the same) and in failing to establish shared metrics (because the names aren't the same). Because the MDMP is top-down, there is an inherent traceability down through the layers. Having established the top-down linkages, the same paths can be traced back up the logical threads until different supporting disciplines can link up to common purpose. Thus, all communities of interest can focus on the specific elements with clarity; define sharing or exclusivity with others; and resolve precedence, dependencies, etc.

To illustrate this concept another way, we can pose this question. When each of the disciplines shown surrounding the thread looks at each of the elements of the Task Cycles and supporting data, to what extent are these elements mostly shared, slightly shared or mutually exclusive? Put more figuratively, are the Venn data sets more like

SYSTEMS-OF-SYSTEMS VIA COLLECTIVE TASKS

When a number of platforms operate together, abstractly they might appear as shown in **Figure 12**. Here effectiveness is no longer simply about individual platforms, but how a collection of platforms performs as a team. For a decade or more, such a collection of platforms has been referred to as a System-of-Systems (SoS). SoS are frequently discussed, particularly with the view that teams of platforms will surely do better than individual platforms. This view seems plausible, but the efficacy of and justification for SoS often seems couched in engineering analyses.

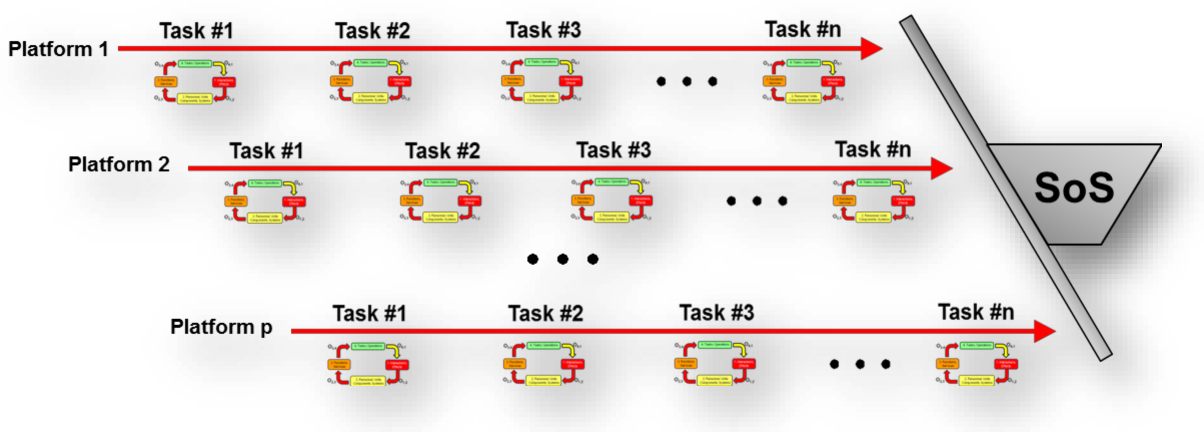

Figure 12. A mission composed of multiple platforms each with its own sequence of Task Cycles. Collections of platforms working together are often referred to as System-of-Systems (SoS). The symbolism to the right is meant to represent the construct of a collective task.

Engineering practice focuses on optional ways platforms can cooperate as well as to show what methods for interoperability can be employed. We suggest that such insights are necessary, but hardly sufficient, to establish insights into SoS efficacy. In particular we note that in the MDMP decomposition process, collective tasks are established by the mission operator prior to assigning individual tasks to particular platforms. To use a football analogy, individual players may qualify for specific positions based on their strength, speed, and athleticism. But in the end, team success is based on the execution of actions defined by the team playbook. Without regard to team activity based on the playbook, the value of the team is in question. Similarly, without the establishment of collective tasks as an integral part of today's warfighting activity, the effectiveness of the DOTMLPF parameter space, including individual people and platform capability, is also in doubt.

LINKING IT ALL TOGETHER

Previously we discussed the notion that vertical linkage between organizational echelons and levels of war is supported by the practice of capturing the externally directed **Level 7, Mission,** and the restated mission derived from analysis of the directed mission. This practice reflects the doctrinal idea of "Nested Concepts". The Operations Process, ADRP 5-0, describes nested concepts as . . . "a planning technique to achieve unity of purpose whereby each succeeding echelon's concept of operations is aligned by purpose with the higher echelon's concept of operations. An effective concept of operations describes how the forces will support the mission of the higher headquarters and how the actions of subordinate units fit together to accomplish the mission. Commanders do this by organizing their forces by purpose. Commanders ensure the primary tasks for each subordinate unit include a purpose that links the completion of that task to achievement of another task, an objective, or an end state condition" (Department of the Army, 2012).

The dotted-blue arrows in **Figure 13** illustrate the 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 it subordinates for its own overall mission effectiveness.

IS THIS SIMPLY THEORY?

The MMF has proven to be both practical and applicable to a range of problem sets. Four projects are cited briefly:

- Testing in a Joint Environment (TJE): The objective of the project was to generate a rational plan for operational test-range employment and investment for a complex SoS. The MMF served three purposes: 1] to organize available information pertinent to OSD T&E, 2] to analyze that information to identify T&E capability gaps in a Joint

Environment, and 3] to provide inputs for a Rough Order-of-Magnitude (ROM) estimation for the corrective investment (Payne et al., 2005). The MMF also informed a detailed analysis of a mission decomposition and functional capabilities crosswalk to set the OT context.

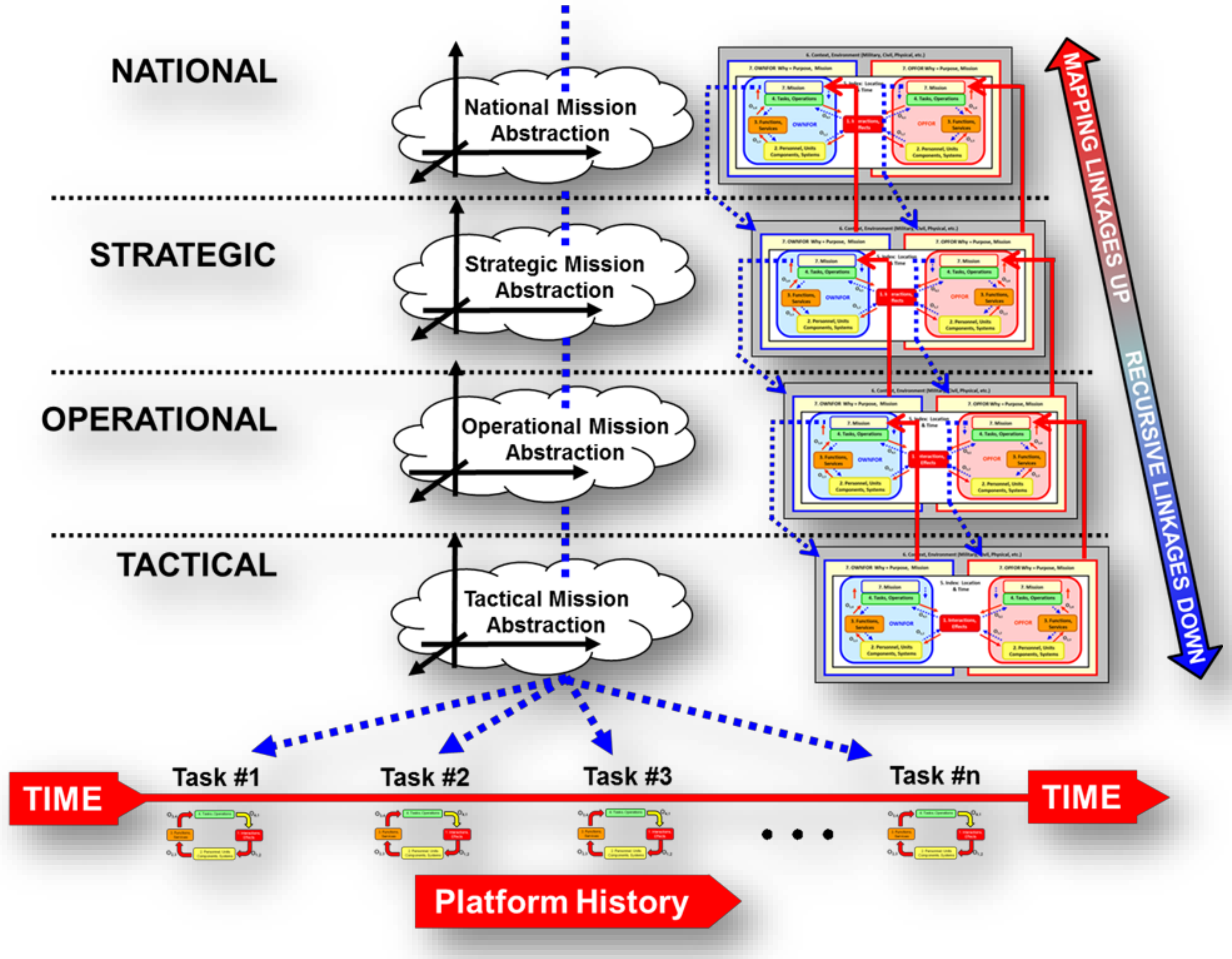

Figure 13. The MMF connectivity by level-of-war (vertically) and in time (horizontally). The MMF has been used to provide an abstract formalism for the MDMP. Its iconic representation, shown on the right, is used recursively to provide logical structure for a top-down (dotted blue) decomposition process and a bottom-up (solid red) assessment process.

- **Stability and Reconstruction Operations (SRO) Micro-Experiment:** This micro-experiment was designed to identify capability gaps associated with an FCS equipped brigade combat team (BCT) performing an SRO mission. The MMF study team developed an analytical model using the EXTEND discrete event simulation environment. The model enabled the team to simulate multiple execution runs of a

180 day SRO mission window and identify tasks that could not be completed to standard due to the loss or degradation of assigned systems (UAMBL, 2005).

- **Managing Intelligence Resources:** This work addressed the challenge of how to deploy and utilize limited intelligence, surveillance and reconnaissance (ISR) resources most effectively in joint-forces operations (Gomez *et al.*, 2007). Using the MMF, modern military doctrine was *captured in a semantically formal representation, allowing sensors and other ISR resources to be assigned to a mission through matchmaking reasoning*.

- **Demonstration of Mission-Based Operational Assessment:** A high-resolution computer simulation was developed to explore the effectiveness of a networked, company-level fighting unit. In the context of collective and platform mission tasks, the analysis tracked 1] the company's ability to continue its mission as a networked SoS while suffering loss of capability in selected components, and 2] the impact of degraded system functions on critical mission tasks. This demonstrated that mission accomplishment at higher levels of combat can be seamlessly linked to functional state changes in low-level components (Ward *et al.*, 2012).

SUMMARY

We have described a framework that builds on the well-established MDMP. This methodology is capable of spanning vertically all levels of war and horizontally over the complete time span of a mission. The MDMP has been enriched through the use of the MMF, which has extended the semantic formalism to key additional elements which exist across all levels of war as illustrated in **Figure 13**.

Full operational context is established in support of sequential task cycling for all materiel/people players and all supporting disciplines. When the "lego" elements, described in **Figure 10**, are developed at this level of resolution, they can be combined in many ways, with great extensibility. This makes possible a single logical construct which can serve the warfighter/operator as well as the modeling/simulation activities. This same construct can be used across many disciplines— theory, modeling and testing, as indeed it must if theoretical abstractions and testing practice are ever to mutually reinforce each other constructively. Only by such practice can validation (comparisons between tests and models) approach its potential and, in the sense of SoS, enable DoD activities to finally become greater than the sum of their parts!

FINAL PERSPECTIVES

DoD Testing/Modeling: Some of the analytic methods, tools, and techniques used today have roots more than 50 years old. The concepts and processes employed, in the main, have arisen independent of one another, mostly in uncoordinated, bottom-up activities.

We therefore have an array of analytic areas characterized by collections of metrics in which commonality or exclusion across disciplines is neither defined nor generally known. Because standard language is often absent, there is imperfect communication of ideas and even metrics between and within communities of practice. Specific analytic and test activities are prosecuted in isolation without the ability to integrate them holistically. We add that this is not a limitation imposed by software "integration" or "engineering." This is a consequence of analysts and coders operating absent a clear concept of the elemental logic pieces of warfighting and/or materiel capability and how the many pieces should properly fit together.

Global Abstract Structure: There are some ironies here. Lanchester established his famous LER methods for estimating warfighting outcome nearly a century ago. Contemporaneous with the initiation of World War II, methods in operations research and system analysis exhibited explosive growth! But the way wargames are prosecuted today remain essentially identical to the concepts and methods established *circa* 1960! If you enquire as to what overall logic or structure informs the DoD either globally at the higher levels of warfighting, or narrowly at lower levels where people/materiel more typically collide with task execution, it would seem we have none! How could this be? Maybe in our collective rush to get the "what" of so many important activities accomplished, we may have skipped past the "why" and "how" of what we are doing!

The absence of what might be called explicit analytic structure has ramifications. As noted previously, the V/L models used from the late 1950s through today are substantially based on lumped-parameter averages, where damage, capability, and utility are conflated. One set of metrics used in direct-fire ballistic V/L analysis goes under the label of "Expected Loss-of-Function." One might think that "Function" has to do with capability or performance, but it actually refers to an unclear notion of mission utility, which mashes physical damage, performance decrement, and mission utility (averaged over a range of unspecified missions) into a number in the range of zero and one! And the word "Expected" would seem to apply to an ensemble average of some sort, but there is no basis for that descriptor either! This imprecision in metric specification contributed to the difficulties encountered by the Army in its Bradley Live Fire program. Also binary kill values (i.e., zero or one) yielded by the lumped parameter approaches are unsuitable to gauge task accomplishment either at the single- platform level or when combined through appropriate logic (see Appendix B), at the SoS level. Thus, to the extent wargames or other simulations fail to represent the state of platform component-level health (**Level 2** state space), there is no way to examine the ways in which systems degrade or reset!

But on the positive side, the challenges of ballistic live-fire programs three decadesago required the Army analytic community to develop the modeling granularity portrayed in **Figure 6**. As we have come to understand more completely this abstraction, it appears increasingly to be a requisite member of an interdisciplinary framework.

Absence of Effectiveness Definitions/Connections: Effectiveness analyses (e.g., requirements, wargames, test, evaluation activities) are not structured in a way that clearly relates system requirements to operational necessity using approved doctrinal terms. Acquisition activities typically proceed without standard, shareable performance and effectiveness metrics. Weapons programs are typically pursued without detailed explanation of the value added and associated risk assessments in operational context. This shortcoming on the acquisition side of the community is ironic because the warfighters through the MDMP have long structured their mission- related activities. And, since the mid-90s, the development of standard task lists has enabled semantic clarity! But the acquisition community still often ignores the task construct, preferring to grapple with capabilities.

Let's consider again SoS. We are unaware of any SoS analysis based upon actual traceability back to task-based requirements in two-sided, multiplatform combat. Tests/analyses all begin with a "Requirements Statement" (or similar document) in which SMEs opined the key metrics, but without the benefit of logical linkage of interconnected team performance (i.e., SoS) actually tied to mission threads evolving over time. The time dimension is critical not only to specifying what must be done in the mission, but also characterizing the ever-changing capabilities of the SoS team based on considerations of accrued damage, repair, logistics, physics of failure, resupply, and many other possible factors. The key to providing this logical linkage of interconnected team performance lies in the use of collective tasks to describe and understand the linkage. As we've emphasized, collective tasks rely on the coordinated and integrated performance of a team of systems assigned to the subordinate and supporting tasks that together form the collective task.

Consider a football metaphor to illustrate the point. One can think of the individual players as systems within the larger SoS that is the team. Each player has a unique set of attributes (e.g., speed, size, strength, passing skill) that must be coordinated and integrated in time and space for every play of the game. Called plays can be compared to collective tasks with each player responsible for executing one or more individual assignments/tasks (e.g., blocking, passing, receiving). Assessing individual football players on their ability to perform their individual assignments is not a valid predictor of team success. It is only when players assemble on the field and execute plays as a team that assessments of potential team success can be made. The effects of accrued injuries, fatigue, medical treatment, rest, and recuperation are well understood in terms of potential impact on the effectiveness of our favorite football teams.

To the best of our knowledge, the collective-task construct stands alone as the warfighter's single defining representation of "combat team" effectiveness! Absent this constructive guiding linkage, there are no activities within the technical design and engineering communities, no matter the skill and dedication expended, that can deliver the effective, suitable, and survivable materiel our warfighters deserve.

Remedies: Improvements must proceed from two directions. By applying the MMF to initial analysis of capstone, operating, and functional concepts, the requirements community, grounded in operational context, can generate products (i.e., mission threads, mission task lists) that are understandable to and immediately usable by the technical/engineering community. Further application of the MMF is needed to analyze and generate products for a set of reference missions that provide that context and give full consideration to the whole DOTMLPF parameter space, not just the materiel piece. The technical/engineering community must learn how to link their parameter spaces back to the warfighter mission threads. It is shown in Deitz et al. (2009, page 120, ff.) that the mission threads are necessary to evaluate the survivability of networked SoS; and the described method relates to any attribute, not just survivability. It is also shown that system or SoS technical performance characteristics (capabilities, component fault trees) can be related directly to mission requirements. Most of the studies and analyses supported by MMF to date have been funded and executed to focus on specific questions at hand. As a result, the tools used to apply aspects of the MMF have typically been developed in a "quick and dirty" fashion to suit relatively narrow purpose. Serious consideration needs to be given to applying the lessons learned to date in order to develop/integrate an MMF tool set to help automate the analytical processes and generate products in standardized, machine executable, as well as human readable formats that can be readily shared and leveraged within and between the two communities.

APPENDIX A: MAPPINGS

Mathematical levels or spaces embody a useful concept to aid in the understanding a process as complicated as the MDMP. A simple way to begin is to examine **Figure A1**.

In this physical example, three individual shadows of an opaque object are shown on three different planes. Each shadow is a valid "projection" of the 3-D object, but also each shadow is an incomplete representation of the object. This is an example of a projection from a higher (more complete) space to a lower (less complete) space. In general, mappings can occur only from higher to lower spaces; thus, they are not invertible. It is this property of noninvertibility that makes top-down processes so critical to providing the most complete array of parameter options when instantiating a multidimensional framework. By contrast, bottom-up processes are appropriate for the (time) execution of mission threads, but not for establishing in isolation a structure (with metrics) for a parameter space. When such *ad hoc* methods are followed, there is no single reference object for varied perspectives to seek common structure. Conceptually speaking, it is this property that can make it difficult for workers in different disciplines to understand the extent to which processes and metrics familiar to them are shared (and how) with other groups.

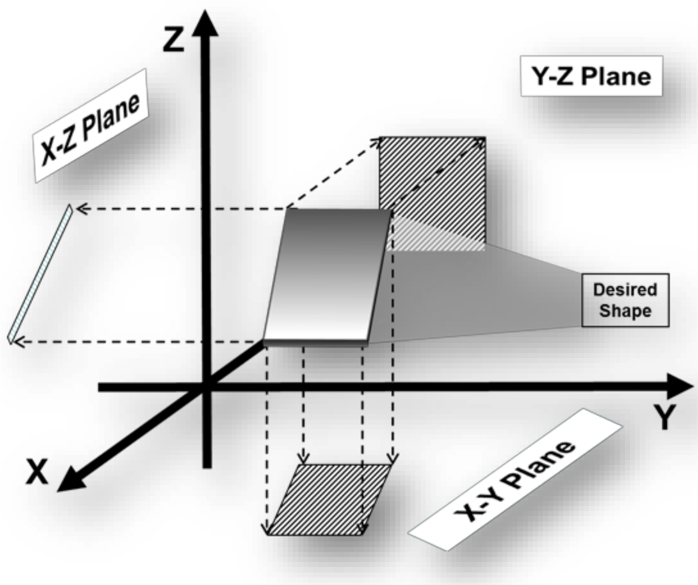

Figure A1. Projections in spaces of differing dimensions. An opaque physical object is located in three-dimensional space. If a light is projected from right to left, parallel to the Y axis, a shadow is cast on the X-Z plane. Likewise, if a light is projected directly downward, parallel to the Z axis, a shadow will be cast on the X-Y plane. So also a light beam projected along the X axis casts another shadow on the Y-Z plane. In this case, the three projections are different, but each provides valid, but incomplete, information concerning the 3-D object.

Figure A2 builds on the example of **Figure A1**, and casts it into an abstract space. The axes <u>do not</u> represent a simple Cartesian coordinate system. In this example, some engineers are contemplating the design of a truck. By virtue of the material properties of the truck, it has certain capabilities to support logistical tasks, to move and maneuver with particular mobility characteristics, and to survive or not when struck by a ballistic threat. The philosophic issue here is which of the properties, fully defined in the actual (3-D) vehicle, have shared projections to the three "planes." In other words, what basic truck properties map to each of the three areas, how are they shared, and how can they be manipulated to an optimum design?

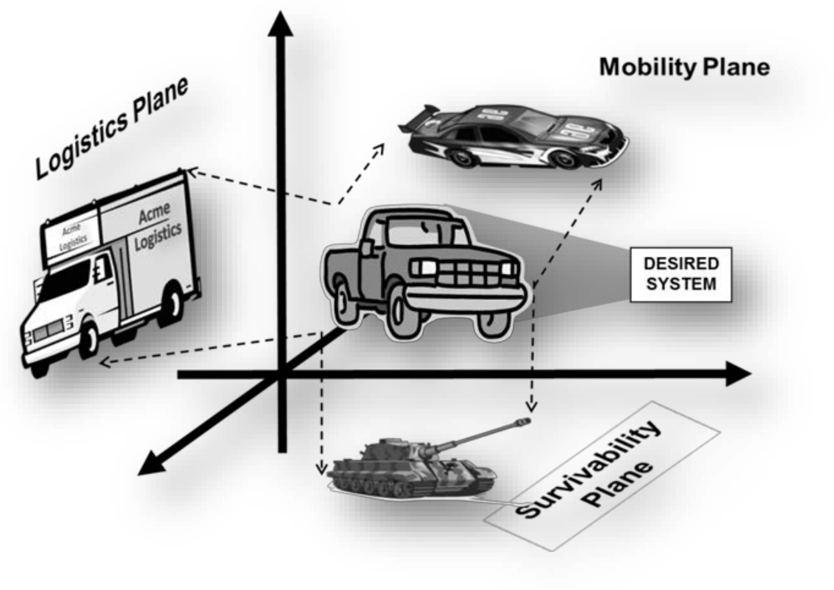

Figure A2. An example of a projection from 3-D to 2-D space. An abstract example of projections from a higher space to three lower spaces. This issue is what truck properties (from the real 3-D) space are identically projected to the three subspaces. Knowledge of the sharing or exclusivity of this can impact performance and, ultimately, platform effectiveness.

But there is an important caveat as we attempt to illustrate the MDMP as an even more abstract set of spaces in **Figure A3.** Because the MDMP is built decompositionally, there do not exist complete spaces of information at one level of war simply to be mapped to a lower space. Many connections are inferential and an important part of the war- planner conceptual activity. So, in the mission build process, whether the linkages are explicitly conveyed or implicitly inferred, this methodology provides significant advantages in understanding the relationships among the complex parameter space.

Our challenge across the numerous "Defense Analytic Challenges" is to understand how the many elements fit together, and where commonality across our many disciplines needs to be identified not only for matters of efficiency but so we can achieve optimum design and process control across the many activities for which the logical linkages are not explicit.

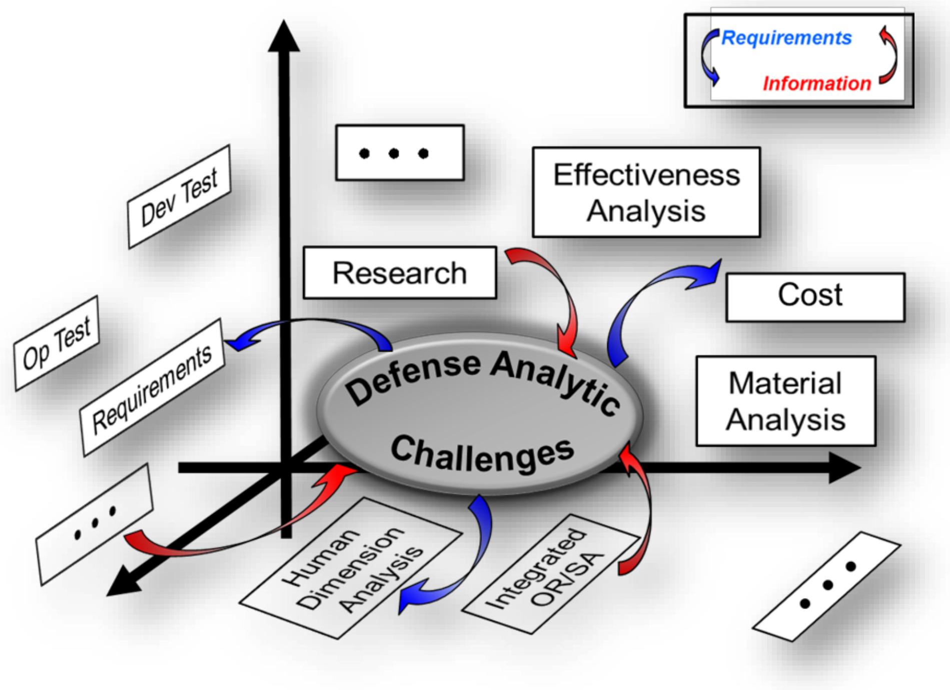

Figure A3. Building on the abstraction of **Figure A2**. Defense Analytic Challenges represent a higher space to the various disciplines displayed as populating lower-level spaces.

APPENDIX B: DETERMINING MISSION READINESS

Applying the MMF to operational analysis is akin to a math teacher requiring the student to "show his work," including all of the intermediate steps, rules, and axioms applied to reach the final answer. For the demonstration of mission-based operational assessment (Ward et al., 2012), the study team needed to describe clearly the steps in the decision-making process used to determine collective task and mission impact resulting from changes in the ability of platforms (aka systems) to execute assigned tasks to standard. Doing so was critical to developing the software logic needed to update the status of platform tasks, collective tasks, and the overall mission during simulation run time. The box in the upper-right corner of **Figure B1** illustrates the process flow for the collective task titled "Manage tactical information". This process flow is an example of the theoretical description in **Figure 12** put to practice. Because most missions are composed of multiple sets of interdependent collective tasks, it is necessary to describe a process flow to link the changing status of critical collective tasks to the resulting impact on the overall mission. The main body of **Figure B1** below illustrates this linkage.

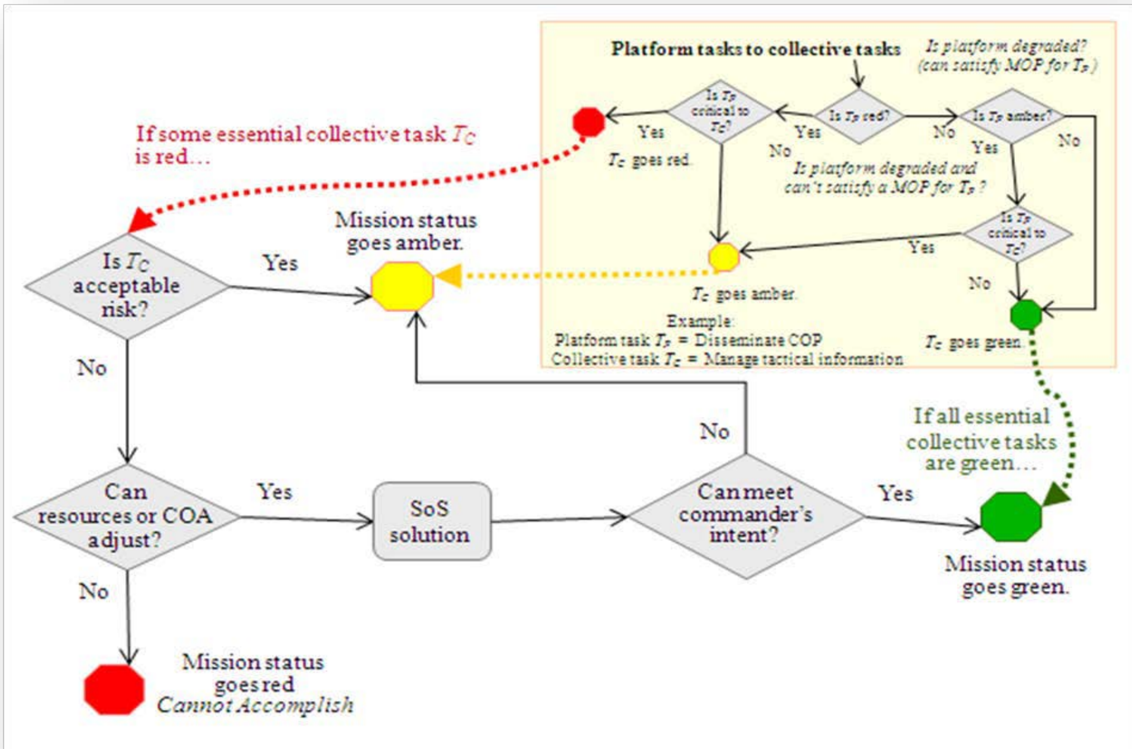

Figure B1. Dependency of collective tasks on platform tasks. Linkage from Platform Task Capability to Collective Task Capability to Mission Impact

The process relies on data collected, stored, and organized in accordance with the MMF structure, based on the results of detailed top-down analysis of the mission. This facilitates the ability to "drill down" and determine the specific factors causing task or mission failure and/or increasing the risk of failure.

APPENDIX C: TEST/ABSTRACTION PARITY

Decision making in the DoD should be based on a process of Knowledge Formation. Our senior managers should be provided appropriate information to sift, filter, analyze, and evaluate various options. This activity is represented at the top of **Figure C1**. The key point here is that there are two paths to **Knowledge Formation**. One is to observe; the other to theorize. In addition to observation, the former path uses exercises, measures, and tests. On the right-hand side, the approach is to calculate, model, represent, and simulate.

Evaluation ("E") takes place in the Knowledge Formation process. Testing ("T") resides on the left-hand, Observe side of the diagram. Modeling & Simulation (M&S) live on the right-hand side.

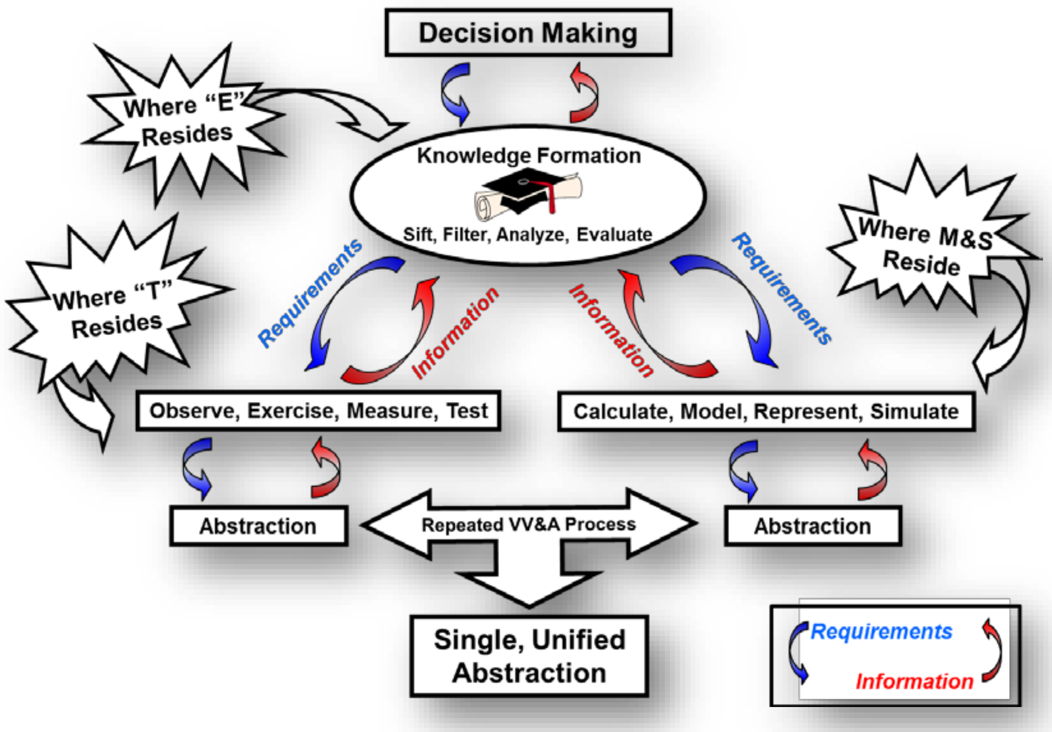

Figure C1. A vision for DoD decision-making. Key knowledge is based on two complementary paths, observation and theory. **Requirements** flow top- down (per blue arrows); Information flows bottom-up (per red arrows). Without an **Abstraction**, or a way of "thinking about an activity", a tester has no idea what to measure, what instrumentation to utilize, or how to process the results.

Most would expect **Abstraction** to be a central part of the right-hand **Calculate** process. After all, simulations are based on abstractions implemented in code and executed by computer. But **Abstraction** is just as much a critical part of **Observation and Testing** as well. For without an abstraction, or a way of "thinking about an activity," a tester would have no idea what to measure, what instrumentation to use, or how to process the results.

What's important here is that 1] both sides have abstractions and 2] that they are harmonized! If not, an activity on one side is logically incompatible with its opposite in <u>kind of metric</u>, <u>level of granularity</u>, <u>time resolution</u>, or some other key property. And without the ability to compare "apples-to-apples," validation cannot take place. Without validation, whatever actual number of tests are performed, it is unlikely that they can be generalized to new and different contexts where the next mission-of-interest may take place. Similarly from the other side, absent validation, the credibility of theoretic and computer exercises remains uncertain and of minimal value.

The need for a single, unified abstraction, appropriate for both paths to knowledge, is the underlying philosophy upon which the MMF is based.

ENDNOTE

The Survivor Sum Rule is based on two key assumptions: first, the parameters being used are true probabilities. Second, they are independent. The computation is straightforward:

$$\mathbf{P_{K\,Total} = 1 - \{ [1 - P_{K1}] \times [1 - P_{K2}] \times [1 - P_{Kn}] \}}$$

In practice, particularly in the vulnerability community, few metrics that are claimed as probabilities are actually so! And as to independence, the likelihood of multiple parameters exhibiting this property is low as well. Whether engaged in a complex mission where many activities are occurring, or evaluating complex war machines with many moving parts, there is a high likelihood that the constituent pieces are closely linked and highly interdependent. It is this cooperation that underwrites the performance and success of military activities and makes dubious any argument that any of their characterizations are independent, one from another!

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An Integrating Framework For Interdisciplinary Military Analyses

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