10th International Command and Control Research and Technology Symposium
The Future of C2

Integrated Architecture-Based Portfolio Investment Strategies

Assessment, Tools, and Metrics, #343

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Abstract

The U.S. Department of Defense (DoD) is in the midst of a far-reaching transformation affecting joint warfighting concepts as well as business and planning practices. Current government guidance establishes DoD policy for managing Information Technology (IT) investments as portfolios to improve business and warfighting outcomes and capabilities. Integrated architectures, based on the DoD Architecture Framework (DoDAF), are an integral component of DoD IT Portfolio Management (ITPM).

At present, architecture-based investment decisions are not prevalent in the DoD. Our research will formalize the development of dynamic "measures of merit" using executable architecture models derived from integrated architectures. These measures, in combination with value assessments and investment cost estimates, will be used within a portfolio analysis model to assess the optimum portfolio of investments based on total portfolio cost and mission-level value (or benefit) within given constraints (e.g., budget). Integrated architecture-based portfolio investment analysis will enable a robust analytical foundation for capability and architecture-based investment decisions and fully support critical DoD transformation goals, guidelines, and policies.

This paper will discuss how we develop integrated and executable architecture models and our toolset environment, provide an overview of portfolio investment analysis and our portfolio analysis tool, and present the way we will link the architecture and portfolio models. A summary of our research is provided at the conclusion of the paper.

Introduction

The U.S. Department of Defense (DoD) is in the midst of a far-reaching transformation affecting joint warfighting concepts as well as business and planning practices. The 2004 DoD *Information Technology Portfolio Management [ITPM]* guidance[1] establishes DoD policy for managing information technology (IT) investments as portfolios to improve business and warfighting outcomes and capabilities.

ITPM states:

- IT investment decisions are based on the Global Information Grid (GIG) Integrated Architecture, …, outcome goals and performance
- Portfolio management processes are established and consist of 4 key activities: *Analysis* of portfolio objectives; *Selection* of the best mix of investments; *Control* to ensure appropriate portfolio management and monitoring; and *Evaluation* to measure contributions towards improved capability.
- Portfolio management processes will leverage the DoD's key Decision Support Systems: The Joint Capabilities Integration and Development System (JCIDS - CJCSI&M 3170); the Defense Acquisition System (DAS - DoDD 5000.1, DoDI 5000.2); and the Planning, Programming, and Budgeting and Execution (PPBE) process.

As indicated above, integrated architectures, based on the DoD Architecture Framework (DoDAF)[2], are an integral component of the ITPM. At present, architecture-based investment decisions are not prevalent in the DoD. Our research seeks to address this "gap" by joining integrated architecture modeling and performance analyses with analytical methods and models used to identify optimal portfolios of investments. A portfolio investment analysis helps decision-makers select the "best" combination (or portfolio) of investments from a set of potential investment options to achieve mission-level objectives and outcomes in a cost-effective manner.

Our research will formalize the development of executable architecture models derived from integrated C2 enterprise architectures and incorporate the results from the application of these models into a portfolio investment analysis tool. C2 is recognized as a critical element of successful military operations and a key aspect of Information Age transformation[3]. C2 is characterized by the strong direct link between human and organizational issues where the organizational design reflects the interaction of tasks to be done, the people available to perform them, and the systems or tools that support them. It is this human dimension that largely distinguishes C2 assessments from other military operation assessments.

Executable architecture models will provide *objective and traceable* "measures of merit" in the context of an end-end mission scenario or capability thread reflecting C2 organization, processes and systems relevant to their assessment. This, in turn, will be used in combination with value assessments and investment cost estimates as the basis for assessing the "best" portfolio of

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1 OSD 03246-04, Information Technology Portfolio Management (ITPM), 22 March 2004, (http://www.acq.osd.mil/dpaptest/Docs/ebiz/itpm.pdf)

2 DOD Architecture Framework, V1.0, Vol. I and II, 15 August 2003.

3 NATO Code of Best Practice for C2 Assessment *Decisionmaker's Guide*, Revised 2002, CCRP Publications

investments based on total portfolio cost and mission-level benefit within given constraints (e.g., budget). Alternate portfolios can be iteratively examined and evaluated by assessing and analyzing their impact within the executable architecture and portfolio models. Integrated architecture-based portfolio analysis fully supports critical DoD transformation goals, guidelines, and policies by showing how to transform and evolve organizations, processes and modes of operation to adapt to new roles, relationships, technologies, and threats.

Developing Integrated and Executable Architecture Models

Before you can use architecture descriptions for any type of analysis purposes, you must first have an architecture that is fully integrated, unambiguous, and consistent. To develop integrated DoD architectures, a new paradigm for architecture development was established – **Activity-Based Methodology (ABM)[4].** This methodology consists of a tool-independent approach to developing fully integrated DoDAF Operational and System views in supporting both "as-is" architectures (where all current elements are known) and "to-be" architectures (where not all future elements are known).

ABM uses a data centric approach for architecture element and product rendering instead of a product centric approach. A data centric approach supports cross-product relationships based on an integrated core set of architecture building block element primitives. It incorporates built-in automation to ensure data consistency that results in quality architecture data and products. This means that the resultant architecture analysis will be more accurate, not subject to misinterpretation and have more value.

ABM captures sufficient representations of "static" activity/information flow architectures models from which they can be transitioned to "dynamic" executable process models. Providing analysis and assessments of complex, dynamic operations and human and system resource interactions supports an overall architecture-based investment strategy whereby architectures are aligned to funding decisions to help drive capabilities, technology investments, and mission objectives and their outcomes.

Data Centric Core Building Blocks of an Integrated Architecture

ABM is based on a set of Operational Architecture (OA) and System Architecture (SA) elements symmetrically aligned to each other from which four OA and four SA architecture elements provide the core building block foundation of an integrated architecture as shown in Figure 1. From these core elements, several DoDAF architecture elements are rendered and several DoDAF products are generated. This enables architects to concentrate on the ***Art and Science of Architectur*e** – that is identifying the core architecture elements, their views and understanding how they are all related together and then performing analysis and other analytical assessments on the subsequent core architecture data, their models, and the generated architecture data.

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[4] Activity-Based Methodology is a concept developed by The MITRE Corporation and Lockheed-Martin, Copyright © 2003

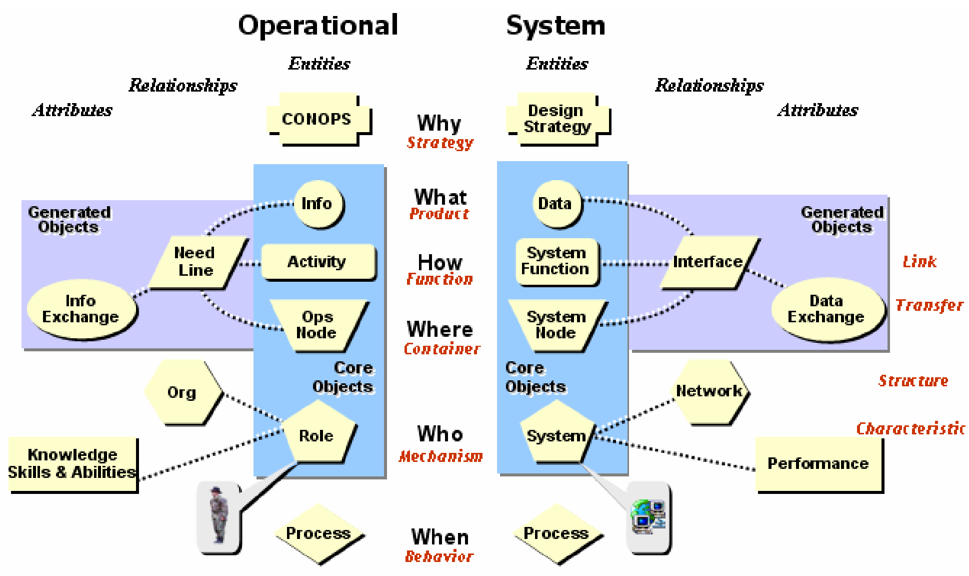

Figure 1. Integrated Architecture Building Blocks

Four primary object entities in each view are considered *core* – i.e., those building block primitives that make up the foundation of an integrated architecture.

Activities (System Functions) – Actions by which input (I) Information (*Data*) is consumed in being transformed to output (O) Information (*Data*). Activities are usually decomposed to sub-activities. They carry dynamic time and costs properties needed in an executable architecture.

Role (System) – Means by which an Activity (*System Function*) is performed, processed or executed. Roles are resources, characterized by a set of Knowledge, Skills and Abilities (KSA) assigned to humans and are analogous to job titles or job responsibilities. Systems are material resources and are described in terms of their performance characteristics. Roles and Systems are grouped together into a collection that represents a physical organization or a requirement for an organization. Systems can be decomposed into sub-systems but Roles can not be decomposed any further. They carry dynamic time and costs properties needed in an executable architecture.

Operational (System) Node – Logical or functional **c**ollections of Roles (*Systems*) performing Activities (*System Functions*). Nodes are usually associated with where roles are located in performing their activities. However since they are considered as collections, they may represent platforms, vehicles, ships, airplanes, Tactical Operational Centers (TOC), Air Operations Centers (AOC), vans, military units, buildings, and even soldiers. Nodes can be decomposed to sub-nodes. They carry no dynamic time properties but have costs associated with them**.**

Information (Data) – Formalized representations of data subject to a transformation process are the inputs and outputs of Activities (*System Functions*). Individual information elements do not have any time/dollar cost properties – it is the information exchange that carries the dynamic time and costs properties needed in an executable architecture.

Associations Between Core Primitives

The associations between the OA/SA sets of core primitives form the basis of an integrated architecture. They are all related to each other such that:

- Each Activity (*System Function*) that produces and consumes information (*Data*) is performed at an Operational (*System*) Node by a Role (*System*)
- Each Operational (*System*) Node contains a Role (*System*) that performs an Activity (*System Function*) that produces and consumes Information (*Data*)
- Each Role (*System*) in an Operational (*System*) Node performs an Activity (*System Function*) that produces and consumes Information (*Data*)
- Information (*Data*) is produced from and consumed by Operational Activities (*System Functions*) performed by Roles (*Systems*) at Operational (*System*) Nodes

The relationships between them can be represented by a triple set of three-way relationships as shown in Figure 2:

1. Operation Node • Activities • Roles
2. System Functions • System Nodes • Systems
3. Organizational Units • Roles • Systems

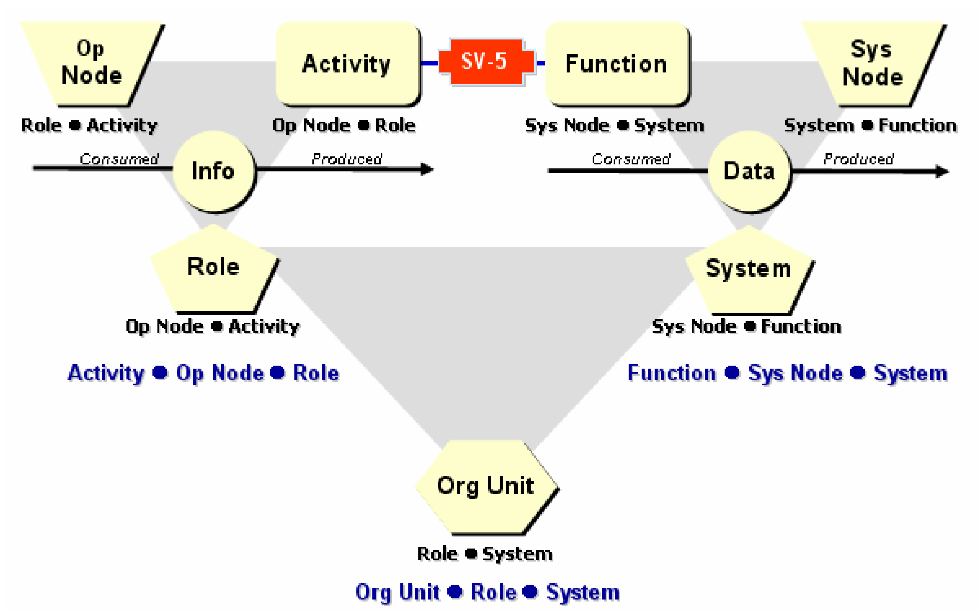

Figure 2. Core Primitives Relationships

Workflow Steps to an Integrated Operational Architecture

The first step to an integrated OA is to create an OV-5 activity model and the first two of the core architecture objects – Activities and Information Inputs/ Outputs. The next step is to create the third core object, Operational Nodes, and then, Roles, the fourth core object, by developing an OV-4 Organizational Chart. At this point, the four core objects have been defined and they can be all associated together via the three-way matrix association. These steps are shown in Figure 3.

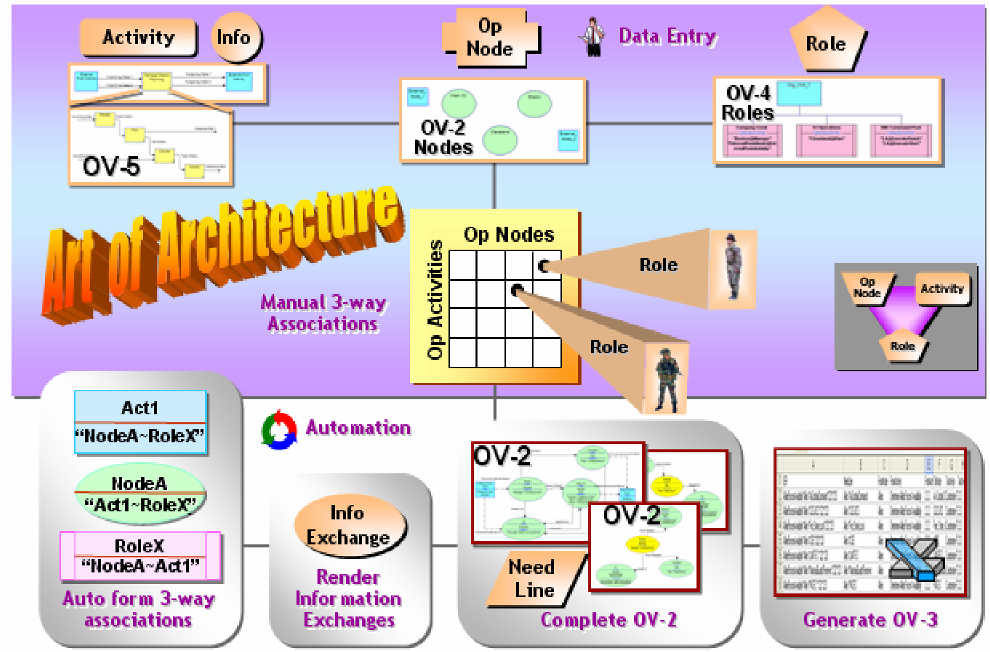

Figure 3. Initial Workflow Steps

These first four steps is what can be referred to as the ***Art of Architectur***e. That is, understanding and identifying what the core architecture objects are and how they are all related together. From this point on, there is sufficient architecture data for automation to take over - generating Need Lines and their related Information Exchanges. An OV-2 can now be completed by auto-connecting each Operation Node pair with their corresponding Need Line. These steps and the subsequent analytical assessments and analysis that can be derived from this generated architecture data can be referred to as the ***Science of Architecture***. The various properties of Information Exchanges are now defined. The set of Information Exchanges together with all their property values becomes the OV-3 product. Finally, candidate activity thread (scenario) models of sequenced actions can be obtained from the set of the leaf activities together with their Information Exchanges. A matching workflow holds for the SA side.

Transition to Executable Architectures

Executable process models enable the associated time-dependent behavior and dollar cost analysis of complex, dynamic operations and human and system resource interactions that cannot be identified or properly understood using static operational models. Note that the cost data developed via the executable architectures is not presently addressed in our research.

Static operational models only show that Activities "must be capable of" producing and consuming Information. They do not provide details on event sequencing or how or under what conditions information is produced/consumed. They also do not explicitly identify, for each activity, the number (capacity) of Roles needed or their ordering for the case when multiple Roles perform the same activity (who operates on the first input, who operates on the second, etc).

Dynamic executable models go beyond "must be capable of" and define precisely under what conditions information is actually produced/consumed and the exact number and ordering of Roles. They define the precise sequential/concurrent event sequencing along with the precise rules and conditions under which information is produced and consumed. Details are also provided on producers and consumers and resources, their number and process ordering and when they are [not] available.

This leads to definition of executable architectures in the context of an integrated architecture from which they are derived. An executable architecture is a *dynamic model of Activities and their event sequencing performed at Operational Nodes by Roles (within Organizations) using Resources (Systems) to produce and consume Information.*

Figure 4 addresses the transition between static and dynamic architectures. The transition is accomplished by starting with the extracted set of leaf activities to which dynamic processing time (duration) and any statistical time distribution, average wait time before processing, continuation strategy, activity cost, and Input/Output conditions are all defined. By connecting and chaining these leaf activities according to the Information Exchanges defined between them, we can produce candidate activity thread (scenario) models of sequenced actions. Information Exchange properties such as transport times including any statistical time distribution, quantity, and cost are already defined in OV-3. Roles and Systems are the human/ material resources used by each process and they have single/ periodic (un)availability times, set up times, capacity (quantity), processing strategies (e.g., first-in, first-out (FIFO), etc.), and hourly and fixed cost. A starting candidate dynamic process scenario model can be automatically generated from an integrated architecture. The candidate model can then be completed in the sense that final behavior is modeled based on exactly how inputs and outputs of each process will be consumed/ produced and any trigger inputs and outputs added.

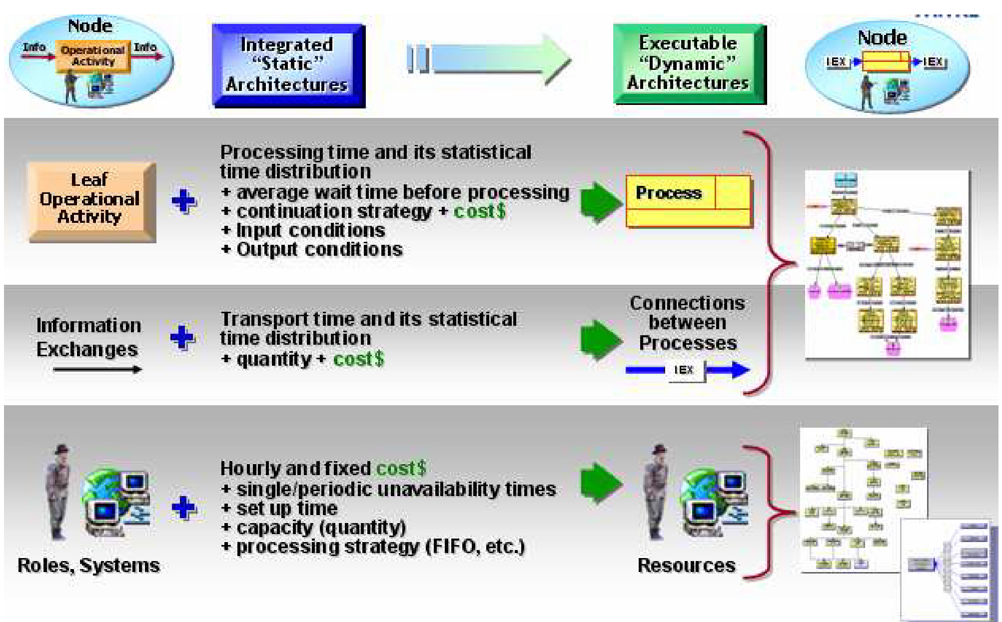

Figure 4. Static to Dynamic Transition

Dynamic Analysis

Dynamic analysis starts by defining a measurable objective – some optimum Measure of Merit (MoM). The next step is to define how to assess and analyze this measure by identifying dynamic model attributes and properties that go into addressing the desired objective and the data needed to complete the measurement. Once all this information is defined and developed, the model is then simulated. The MoM can then be assessed and based on how well the overall objective was met (or not met), the model can be edited, re-simulated and the MoM assessed again. This repeats until an optimum MoM is reached. The executable model also assesses the related measures of performance that support the overall MoM – it is the performance measures that are applied in the investment analysis. Application of these measures will be discussed further in the "Linkage" section of this paper.

Tool Environment

Figure 5 represents our tool environment to linking integrated and executable architecture with portfolio investment analysis. We start by building integrated architectures using Popkin's System Architect with their DoDAF/ABM option (www.popkin.com). System Architect is an enterprise architecture modeling tool widely used throughout the government and DoD. Our integrated architecture will then be transitioned to an executable architecture in our Modeling and Simulation (M&S) tool – Bonapart (www.pikos.net). This is an object-oriented business process modeling tool based on a Colored Petri-Net (CPN) simulation engine. MS Excel and MS Access provide further analysis of our dynamic "executable" model.

Our integrated architectures combined with simulation tools and scenarios, and analytical tools and methods render quantitative actionable architecture information in what we call "actionable architectures". This information can be used for any number of purposes. The main purpose in our research is to support investment decisions and to produce an "actionable portfolio investment strategy" that organizations can directly act on. Our portfolio analysis tool is the portfolio analysis machine – PALMA™ – a decision support tool developed by MITRE that facilitates capability-based investment planning. PALMA is further explained in the next section.

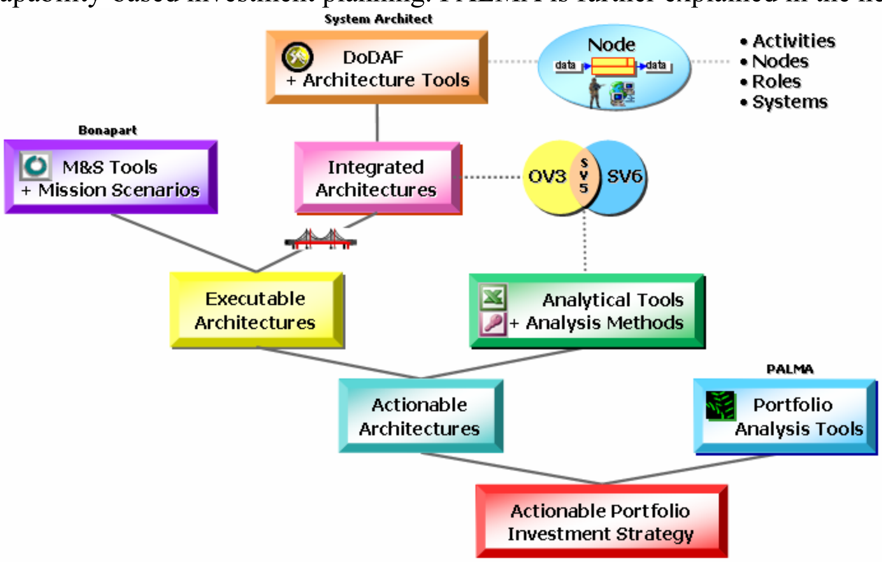

Figure 5. Tool Environment

Portfolio Investment Analysis

Background/Overview

The relationship between investments, portfolios and portfolio investment analysis is quite intuitive if one considers the stock market. An *investment* is something that a person spends his money on – such as a particular stock or a particular bond. A *portfolio* is a collection of investments – such as a combination of various stocks and various bonds. A portfolio investment analysis is a process for assessing the pros and cons of different combinations of investments based on specific financial goals (e.g., growth).

In the DoD's enterprise, an investment is something on which an organization spends its money. A DoD investment could be a materiel resource (a person, a facility, equipment, a platform, ...) or a non-materiel resource (training, a service, etc.). A portfolio in the context of the DoD is a set of investments that achieve a mission, an effect or a capability.

A portfolio investment analysis, then, is the analytic process by which decision makers select the "best" combination of investments (i.e. the "best" portfolio) from a set of possible investments. By "best," we mean the most cost effective portfolio for achieving a mission-level objective, an effect or a capability within given constraints. When done well, a portfolio investment analysis provides the decision-makers with additional insight into the decision-space and the possible trade-offs based on mission needs. Important elements of a robust and effective portfolio investment analysis include:

- Use of a repeatable and traceable process
- Use of a consistent data set across the investments being considered
- Ability to relate the impact of any set of investment options to achievement of high level "strategic" objectives
- Selecting the best mix of investments in context of portfolio(s) in which they reside
- Ability to measure improvements of investments and analyze their consistency with core mission goals
- Ability to identify common capabilities in order to achieve cost reductions.

The Portfolio Analysis Machine (PALMA™) – An Investment Analysis Tool

PALMA models how an overall mission's success depends upon the conduct of individual activities. Activities are supported by material and non-material investments. PALMA requires specific inputs:

- Investment options - their cost and what they do for you (detailed impacts)
- How it all fits into your overall goals (hierarchical decomposition of mission needs)

A mission goal is decomposed into its constituent activities, creating a "strategy-to-task" hierarchy tree. "As-is" conduct of activities is related to the "baseline" (or current) *value* they provide to the mission in the PALMA "strategy-to-task" tree through a "scoring" process. The value of each activity is measured on a scale from 0-100, with color representations for different parts of the scale (e.g., red = 0-25, yellow = 26-50, etc). To determine the overall mission score based on the activity scores, roll-up rules are created. Roll up rules identify the mathematical relationship between the "parent task" and its "children" as shown in Figure 6 below. Roll-up rules are created for all parent-children relationships.

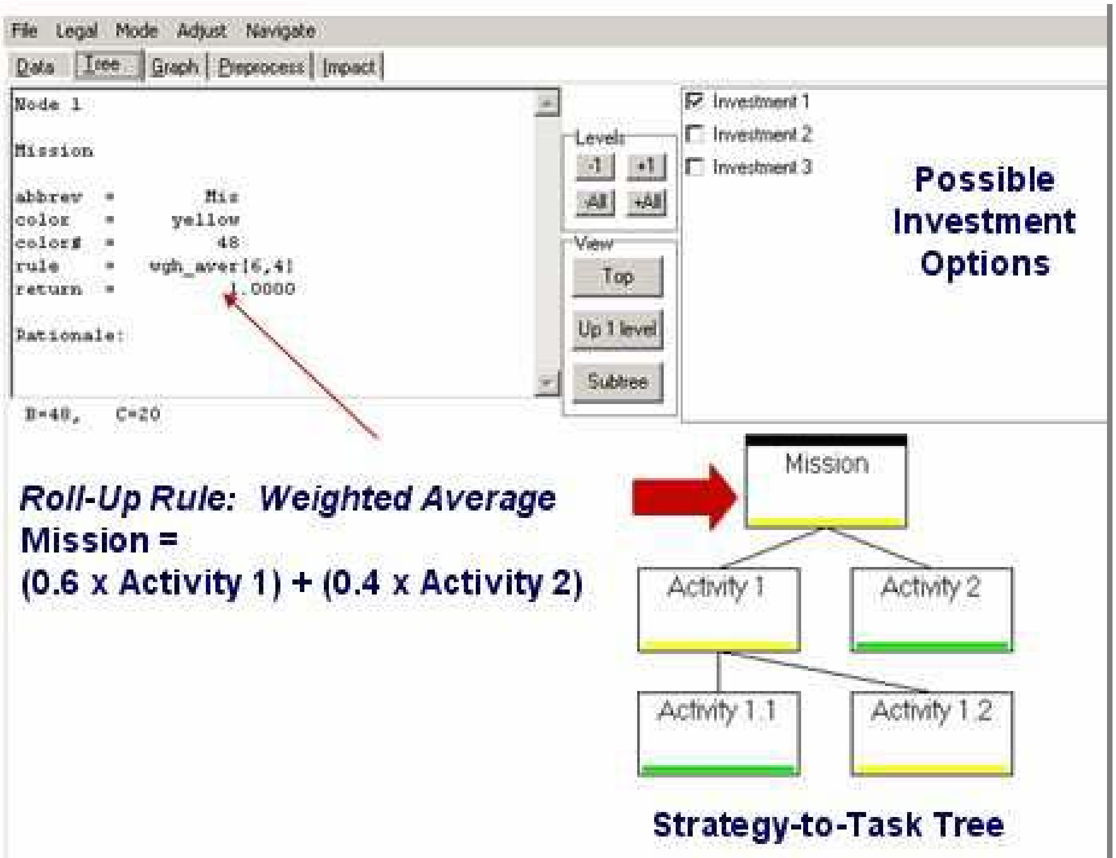

Figure 6. Example PALMA Tree and Roll-Up Rule

For each investment, we determine the increase in value that would occur for each activity that the investment impacts (e.g., if investment 1 is purchased, the value of activity 1.1 will change from 30 to 60). With all data collected, the PALMA model can be fully constructed. Once constructed, PALMA optimization algorithms are used to identify the "efficient frontier" – optimal portfolios (and options in each) that provide the greatest overall benefit (y axis) for a specific budget or funding level (x-axis). Figure 7 presents a notional efficient frontier (black points), with a single portfolio selected (red point, encircled). This portfolio requires a budget of $200, achieves a value of 58 (here "green") and contains investment N2 and M5.

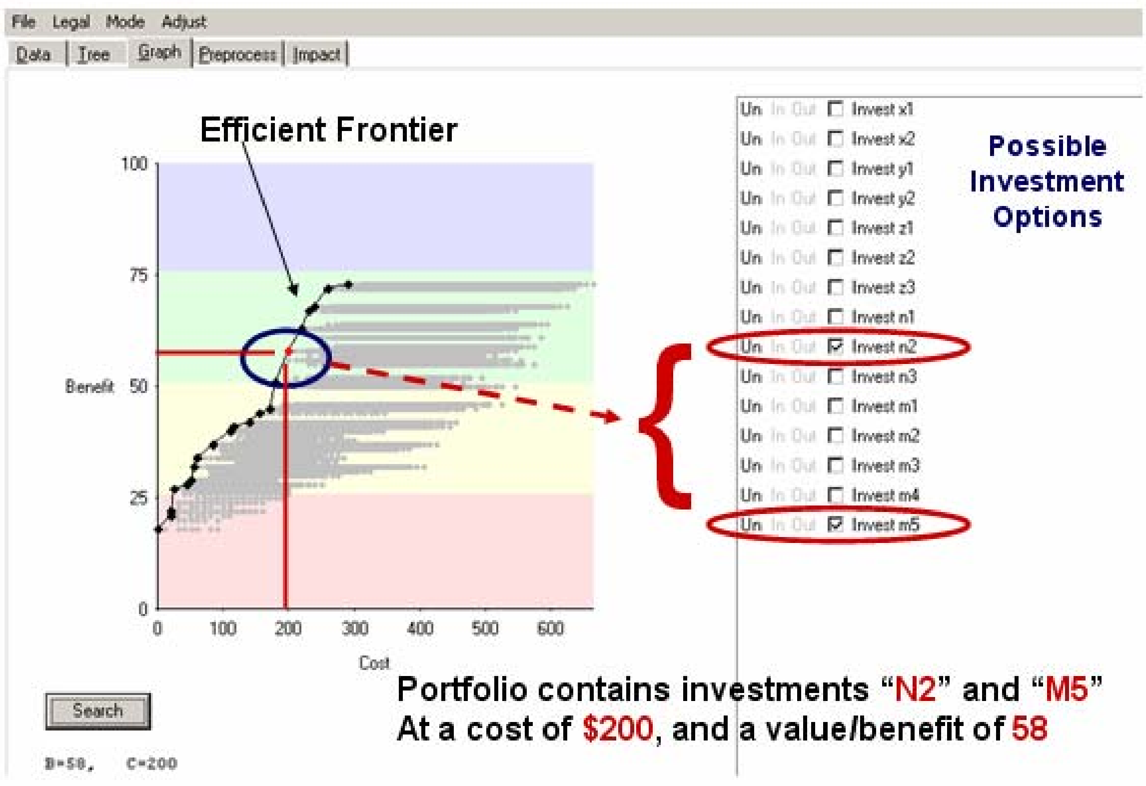

Figure 7. Example PALMA Efficient Frontier

Key features of PALMA include:

- Sophisticated search algorithms that derive optimal (greatest benefit at the least cost) portfolios
- Ability to plan investment options over multiple years
- Ability to model complex interdependencies among options
- Ability to identify critical paths in the strategy-to-task tree, so that for any model, one can determine where to direct a new investment to create the greatest marginal benefit
- Ability to conduct a variety of "what-if" scenarios

Steps to Linking Executable Models with Portfolio Investment Analysis

The linking of executable models to portfolio investment selection is depicted below. Infusing objective measurements into the PALMA "scoring" process provides a more direct, objective and repeatable assessment of value. Rather than relying solely on "experiential assessments" from subject matter experts (SMEs) or from other non-architecture-based models, investments are "scored" based on outputs from the integrated and executable architecture models and their dynamic analysis and combined with value assessments developed by SMEs The process is depicted in Figure 8 below followed by a description of each step.

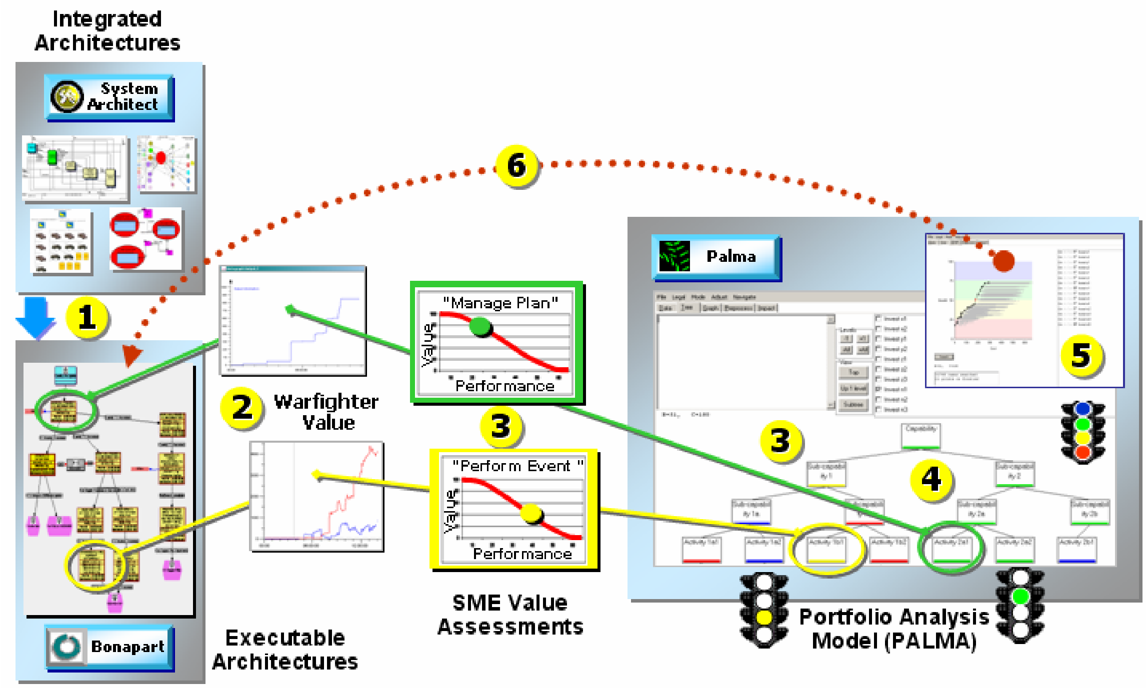

Figure 8. Overall Process

1. Build executable model starting with DoDAF architecture products produced via ABM and transition to executable model.
2. Complete baseline performance assessments of leaf-level processes by assessing objective performance measurement of activities and their resources (systems and people) in the context of an end-end (input-output) execution thread in the executable model.
3. Derive "strategy-to-task" PALMA "tree" from executable model. Performance data is translated from the executable model (step 2) into PALMA "baseline score" for each activity via a value function curve assessed by SMEs. These value functions relate specific levels of "performance" to specific values in the PALMA scale (0-100). Infusing executable architecture data refines SME judgments by tying them more closely with the SME's actual experience. It asks the SME to determine the value of a given performance level, not the value of a given investment. SME judgments are being applied to objective, consistent and validated data. Previously, SME judgments were responsible for

evaluating both performance and value. Now SME judgments will evaluate value but not performance.

4. Define roll-up rules that address the relationships between elements in the PALMA model based on the executable architecture model.

   Identify investment options and their cost. To obtain a value "score" for each possible individual investment option, we use a PALMA mathematical model (using a queuing theory formula within PALMA as shown below) that determines the impact each investment would have on the baseline score (i.e., how would it change the score).

   Investment options include adding more resources (increasing capacity), reducing the execution time of the task (decreasing service rate), and/or reducing the arrival rate of incoming tasks (decreasing demand on resource). By calculating these possible investments and their combinations, we avoid the need to run the executable architecture model for each possible combination set of investment options.

$$t = \frac{\left(\frac{\lambda}{s\,\mu}\right)^{\sqrt{s}}}{s\,\mu - \lambda} + \frac{1}{\mu}$$

   Where t = total time to complete a task,

   s = capacity of the resource that performs the task,

   μ = rate of service for the resource that performs the task

   λ = demand on the resource that performs the task

5. Generate the Efficient Frontier. PALMA performs an optimization analysis of the complete set of combinations of all possible individual investments. It does this by calculating the impacts of the various combinations of investments based upon the relationships modeled in the "strategy-to-task" PALMA tree and then comparing that benefit to the costs of those investments. This process also provides a robust accounting for the synergies between investments.

6. Once a complete set of optimal portfolios has been obtained, each portfolio can be further evaluated by going back to the executable model and modifying the baseline by adding the investments of a specific portfolio. This "back-and-forth" between PALMA results and the executable model allows the robustness of solutions to be well-tested.

This process involves considerable interaction between the analyst, the decision-maker and other stakeholders to ensure critical elements of the analysis are understood, agreed to and executed appropriately. Once complete, the analysis is summarized to provide an actionable investment strategy for the decision-maker. The final report is structured to provide insight to the overall process and traceability from analysis inputs to final results.

Summary

Linking integrated architectures with portfolio investment analysis has wide applicability within DoD and other government agencies. It promotes investment decisions that are directly linked to mission objectives and their outcomes. It also provides a robust analytical foundation for capability and architecture-based portfolio investment decisions. This effort also demonstrates the value of architectures in a decision-making context. Alternate portfolio investment strategies can be iteratively examined and evaluated by assessing and analyzing their impact on the architecture and portfolio models. Directly linking objective "measures of merit", developed via executable architectures, to an investment portfolio optimization can improve identification of critical mission capabilities (keep), unnecessary duplication of mission elements (eliminate), and gaps/deficiencies (recommend new solutions). Integrated architecture-based portfolio analysis fully supports critical DoD transformation goals, guidelines, and policies by showing how to transform and evolve organizations, processes and modes of operation to adapt to new roles, relationships, technologies, and threats. It has the potential to be a key tool in making DoD transformation objectives a reality.

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