The Work Breakdown Structure in the Systems Engineering Process

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Abstract

Many textbooks, handbooks, standards, and guidance documents approach the Work Breakdown Structure (WBS) exclusively from a project management perspective. This may result in the systems engineering team overlooking the WBS as a key systems engineering artifact, or worse—a WBS that does not serve to effectively integrate the technical and programmatic elements of the project. This paper examines the WBS and addresses how, when structured and used appropriately, the WBS documents the overall system architecture and integrates the elements of the project to provide the insight necessary for the analysis and decisions required for effective systems management.

Introduction

Development projects generate *products*, and the definition and delivery of these *products* is the focus of systems engineering. We suggest that the Work Breakdown Structure (WBS) is the fundamental tool for the organization and integration of the products and all associated efforts to build them. The WBS captures and documents the product definition and integrates that perspective with a list of the work necessary to complete the project. The integration of the project technical elements and the management elements provides the basis for successful and timely development, integration, deployment, and sustainment of a system.

We strongly believe that a product-based WBS is fundamentally a systems engineering artifact that captures the decomposition of the system developed by the project team. Unfortunately, many textbooks, handbooks, standards, and guidance documents approach the WBS exclusively from a project management perspective. This may result in the systems engineering team overlooking the WBS as a valuable systems engineering artifact, or worse—a WBS that does not serve to effectively integrate the elements of the project.

The WBS is the artifact that ties together project scope, risk, schedule and resources into a coherent systems management framework. The WBS logically decomposes the system into its component parts. It establishes a master list of all the work that must be accomplished for those components to be realized and integrated into an accepted system, and it is the basis from which tasks and activities are scheduled, risks identified and resources assigned.

This paper will examine the WBS and address how it can be a key tool for the systems engineering team. When structured and used appropriately, the WBS documents the overall system architecture and integrates the elements of the project to provide the insight necessary for the analysis and decisions required for effective systems management.

Context

In its basic form, the WBS is a document that identifies and organizes all the work to be accomplished in creating a product or system. Fundamentally, the WBS defines and captures the decomposition of a system of interest by dividing the total product into successively smaller and more manageable entities or components. This system decomposition provides the systems engineering team and project leaders the opportunity to ensure that all required elements of the system are identified in terms of allocated technical performance goals. It can also ensure that all work associated with those products is planned and monitored.

In addition to defining the basic organization of the project, the WBS usually also:

- Ties directly to the configuration management process through the system requirements, specifications, designs, or drawings that describe the various configuration items.
- Provides the basis for identification of the project tasks or activities that become the Integrated Master Plan and Integrated Master Schedule.
- Integrates the resources and resulting cost and earned value reporting.
- Integrates the technical, schedule, and cost components at the working level and provides a logical structure for summarization to the project or system level.
- Associates project risks to the areas of the project they affect.

Current U.S. Department of Defense guidance requires that a program WBS be established to provide a framework for program and technical planning, cost estimating, resource allocation, performance measurement, and status reporting (DoD Directive 5000.1 and DoD Instruction 5000.2 are germane). The *Department Of Defense Handbook - Work Breakdown Structures for Defense Materiel Items* states:

> *The Program WBS provides a framework for specifying program objectives. It defines the program in terms of hierarchically related, product-oriented elements and includes "other Government" elements (i.e., Program Office Operations, Manpower, Government Furnished Equipment (GFE), Government Testing). Each element provides logical summary levels for assessing technical accomplishments, supporting the required event-based technical reviews, and for measuring cost and schedule performance.*
>
> (MIL-HDBK-881A, 30 July 2005, p.2)

The National Aeronautics and Space Administration (NASA) provides similar guidance:

> *A WBS is developed by first identifying the system or project end item to be structured, and then successively subdividing it into increasingly detailed and manageable subsidiary work products or elements. Most of these elements are the direct result of work (e.g., assemblies, subassemblies, and components), while others are simply the aggregation of selected products into logical sets (e.g., buildings and utilities) for*

management control purposes. In either case, the subsidiary work product has its own set of goals and objectives which must be met in order for the project objectives to be met. Detailed tasks which must be performed to satisfy the subsidiary work product goals and objectives are then identified and defined for each work product or element on which work will be performed.
(NASA Work Breakdown Structure Reference Guide, May 1994, p. 1)

We do not intend to imply that the WBS is a tool that only applies to projects in the government domain. The WBS is a useful tool for *all* projects. A well-documented WBS enables a number of key systems engineering decisions as illustrated in the Figure 1. Similarly, the technical decisions documented by the WBS artifact affect or are affected by a number of the systems engineering processes in every phase of the development lifecycle.

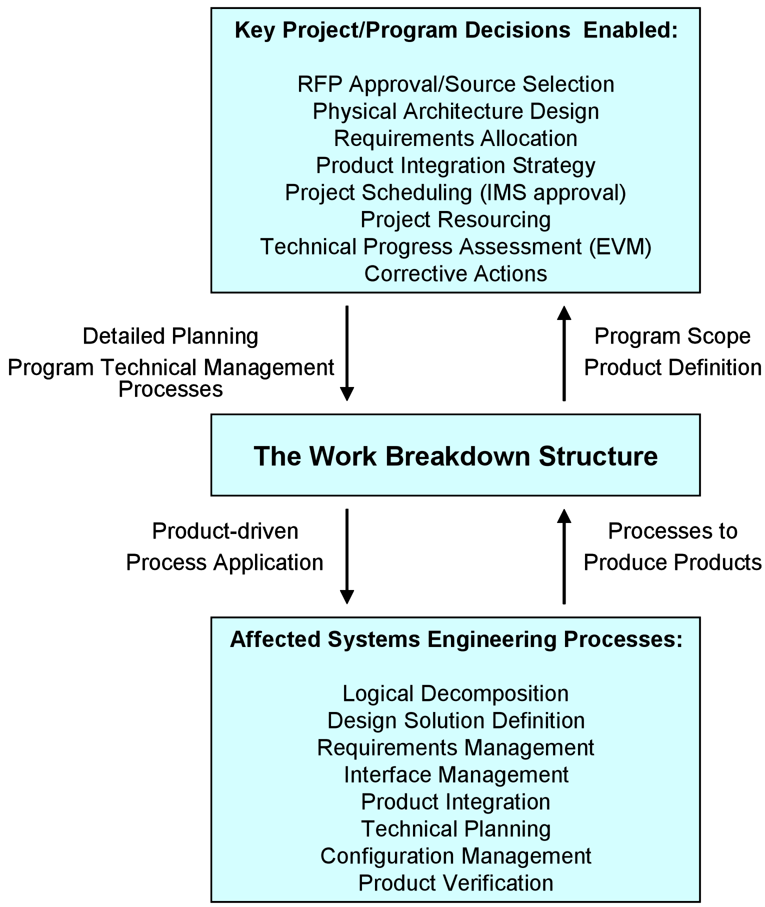

Figure 1. WBS Context

What is a WBS?

The WBS is usually defined as a "product-oriented family tree" that organizes and integrates the work, people and processes on a project. While this is not the only acceptable approach to creating the WBS, the product-based WBS has been shown to improve the effectiveness and success of system development efforts. Figure 2 illustrates an example system decomposition from the overall system level to the individual units that make up the system. The units (lowest level) could be further decomposed, if necessary, to reflect individual configuration items.

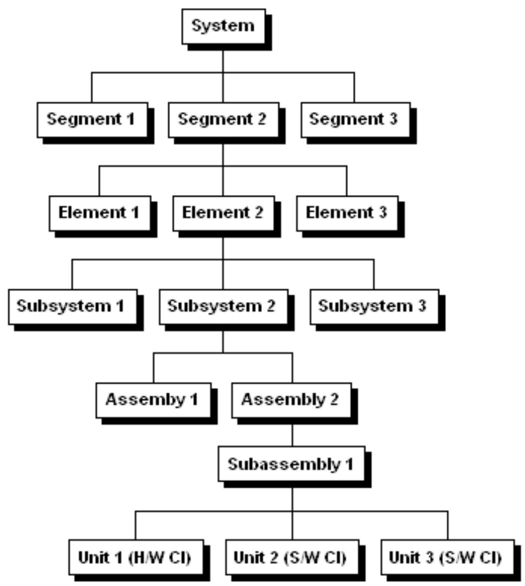

Figure 2. Example System Decomposition

Figure 2 illustrates a WBS developed from the perspective of the elements that comprise the system physical architecture—usually referred to as a system Product Breakdown Structure (PBS). Each of the boxes in Figure 2 represents a level of the system decomposition to define how the system components: segments, elements, subsystems, assemblies, subassemblies, and units or configuration items relate to one another, along with the associated documentation for design, definition, procurement, or manufacturing as appropriate. Each box would also be assigned an individual responsible for planning and executing the effort to provide the product defined for the box.

A fundamental purpose of the WBS is to control development activities in the context of system decomposition. Therefore, the WBS must be sufficiently detailed to grant the project manager and the lead systems engineer sufficient insight for the level of control appropriate to the project through all phases of development. Too much detail in the WBS can become distracting, not to mention too time-consuming to document and maintain. Typically the "right" level of WBS is one that decomposes the system to the logical assignment of work to an individual or team, with a clear definition of the desired work product and a defined logical intersection with dependent or related work products. The purpose of the WBS is *not* to enable the project manager or systems engineer to micro-manage every task associated with the project. Rather, its purpose is to describe the system physical architecture and associated work with enough fidelity to enable project leaders to hold subordinates accountable for specific achievements.

For the purpose of this paper, our assumption is that the system architect has already decomposed requirements and allocated them to the functional architecture and then to the various system components in the physical architecture. The architecture development process is non-trivial and iterative at all levels of system decomposition. Once a stable architecture is decided, however, a product-based WBS may be defined from the physical architecture that is represented by the PBS. This will include all system hardware, software, documentation, training, and other key system pieces. The WBS then becomes part of the project technical baseline and must be managed as an element of the project configuration management process.

In addition to the product-based approach, the WBS may take other forms, depending on who developed it and their objectives. Other WBS formats may include:

- Time: organized around project phases
- Funding: tied to a contract payment structure
- Functional: reflects the technical staffing structure within the organization performing the work
- Implementation approach: ties to the iterations, builds, increments, or evolution of the system

Whatever the approach, the WBS must identify the products or work to be performed within its structure. As suggested thus far, the WBS construct most useful to the systems engineering team is a product-based, logical model of all the hardware, software, services, data, and facilities relevant to a given system of interest. The example depicted in Figure 3 visually illustrates that one can see at a glance that the Correlator and Analysis Tool Suite are integrated into the Correlations & Analysis Engine before the Data Warehouse, Operational Data Store, Correlations & Analysis Engine and Performance Tools are integrated into the overall Processing System.

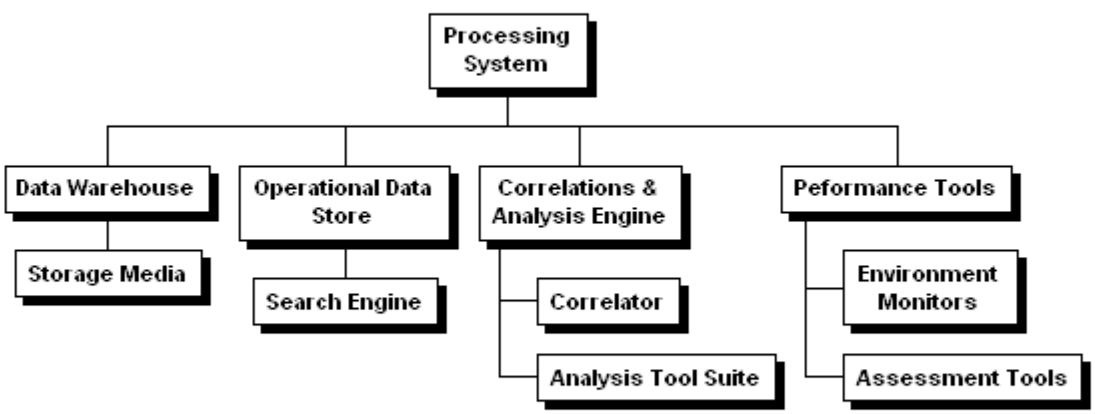

Figure 3. Example Product-Based WBS

The functional or task-based WBS (Figure 4) is often used in organizations with weak project management organizations. Typical functional categories might include: software, electrical design, machining, or purchasing. This type of WBS does not serve to document the system architecture. Consequently, the Project Manager becomes the only person formally responsible for any tangible system element, since there is no product breakdown below the system level. That said, some functional categories will always appear on a product-based WBS. For example, project management and systems engineering are two functional categories that are commonly documented in a WBS.

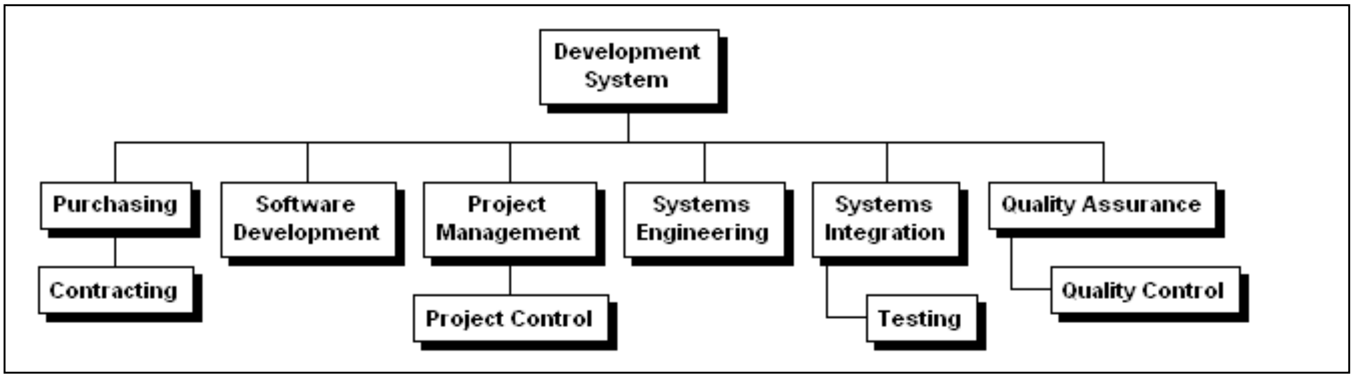

Figure 4. Sample Task-Based WBS

Of all the basic WBS formats, the "family tree" format is best suited to illustrate the system physical decomposition and integration strategy, as well as to organize and integrate the work, people and processes on a project. (Figure 5)

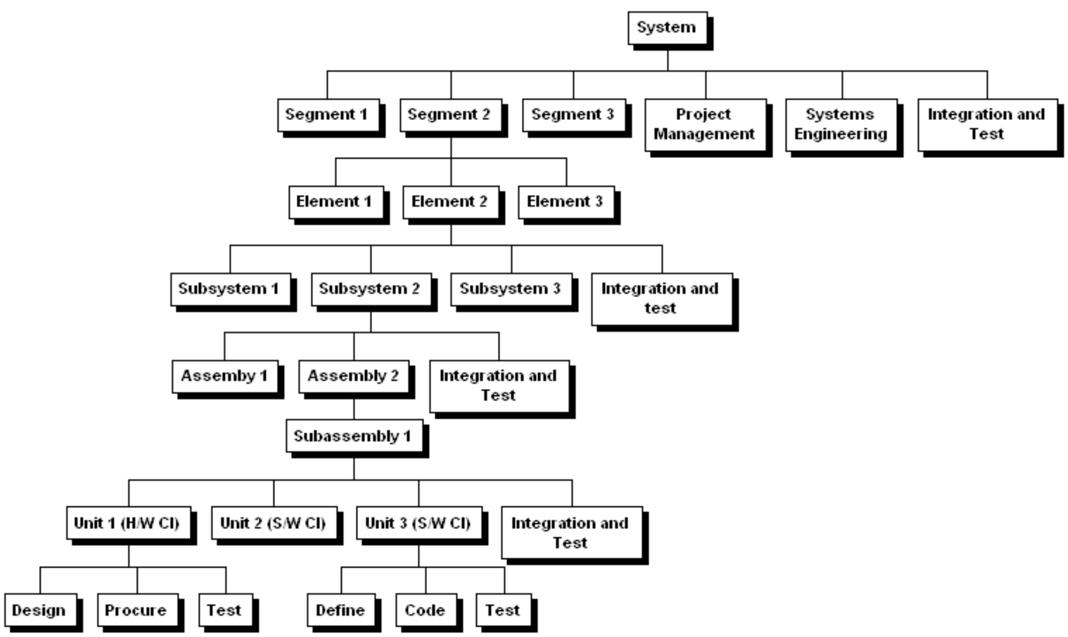

Figure 5. Product-Based WBS Tree

Another common method for documenting a WBS is the numbered or indented list, which uses a numbering scheme that may be used for cross-referencing other system artifacts. Figure 6 documents a WBS to eight levels using the indented list format. While it may be more convenient to document the WBS using the indented list structure, it is often easier to visualize the system integration strategy from the hierarchical tree perspective.

```
1.0 System
  2.1 Segment 1
  2.2 Segment 2
    2.2.1 Element 1
    2.2.2 Element 2
      2.2.2.1 Subsystem 1
      2.2.2.2 Subsystem 2
        2.2.2.2.1 Assembly 1
        2.2.2.2.2 Assembly 2
          2.2.2.2.2.1 Subassembly 1
            2.2.2.2.2.1.1 Unit 1
              2.2.2.2.2.1.1.1 Design
              2.2.2.2.2.1.1.2 Procure
              2.2.2.2.2.1.1.3 Test
            2.1.2.2.2.2.1.2 Unit 2
            2.2.2.2.2.1.3 Unit 3
            2.2.2.2.2.1.4 Unit Integration and Test
          2.2.2.2.3 Assembly 3
          2.2.2.2.4 Assembly Integration and Test
      2.2.2.3 Subsystem Integration and Test
    2.2.3 Element 3
    2.2.3 Element Integration and Test
  2.3 Segment 3
  2.4 Project Management
  2.5 Systems Engineering
  2.6 Segment Integration and Test
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Figure 6. Indented List WBS

Importance of the WBS

The WBS provides the framework for defining and managing development of the system's technical objectives. By dividing the total product into successively smaller entities, the systems engineering team and project leaders can use the WBS to ensure that all required products are identified in terms of overall system technical performance goals and that all work associated with those products is planned and monitored. The WBS reflects the specification tree and configuration items, and it enables verification and validation planning by defining the test and evaluation plan at each level of system decomposition.

Simply stated, the WBS provides a framework for organizing development activities for a given system of interest. The WBS identifies the total work to be performed to a specified level of detail and ties the products and the work associated with those products to those responsible for the work. It is the foundation for all project planning and resource estimating and it creates the logical summary of detailed information for management and reporting. The WBS also enables tracking using Earned Value management techniques by defining Control Accounts and their associated Work Packages, or the unit of work represented by the task boxes on the WBS.

Using a WBS for Project Status

In a well structured project, the WBS becomes the link between the technical, schedule, and cost elements. This is readily seen in a project that requires development of an Integrated Master Plan

(IMP), Integrated Master Schedule (IMS), and an Earned Value Management (EVM) baseline. Together, these three elements are the foundation of a structured management and reporting system.

The IMP provides an event-driven plan that details what must be accomplished for project success. This plan begins with major project “events,” which are then decomposed to the “accomplishments” necessary to successfully achieve the events. Each accomplishment is composed of criteria that, when fully completed, equate to successful fulfillment of the accomplishment. Through this process, project leaders can maintain clear insight to the technical (i.e., development) progress necessary to achieve the technical results of the project. For example, one project “event” is the Critical Design Review (CDR); one “accomplishment” associated with the CDR is approval of the Final Bill of Material (BOM); and one associated criterion for this “accomplishment” is sign off of each drawing. Thus, success at CDR requires a BOM and the BOM cannot be finalized until the drawings are approved.

Each IMP criteria is mapped to a WBS element (note: mapping may occur at the accomplishment level) and is further decomposed into the activities that become the basis of the Integrated Master Schedule (IMS). The IMS links the activities developed from the IMP Criteria into a logical performance order, along with estimates for the duration / effort to accomplish each activity. When processed into a scheduling tool, this information can be used to generate a critical path network, an estimate of the dates for each activity, resource usage, as well as other useful management information. This logical structure can be summarized to the IMP or the WBS in order to understand the overall project status.

The EVM process uses the resources (type, quantity, and duration) from the schedule to calculate the expected cost of each effort. When combined with an Earned Value Technique for claiming performance, this becomes the Performance Measurement Baseline (PMB). Through this process, the PMB integrates the required outcomes defined in the IMP with the timing of the work from the IMS to the cost and provides a basis for performance assessment.

For performance assessment, status is reported by claiming progress against an earned value technique that calculates the earned value (Cost of Work Performed). When combined with the actual costs accrued in the accounting system all three earned value parameters (planned / earned value / actual) are available for earned value assessment and analysis. This information also provides the schedule status which summarizes to status the criteria, accomplishment, and event.

Properly done, this process captures the system development cycle (systems engineering process / technical baseline development) by capturing the critical milestones (events) and the accomplishments / criteria that lead up to them. The WBS then provides the ability to trace the development cycle to each of the products, processes, and activities necessary for project success.

The WBS in the Systems Engineering Process

The WBS is the foundation of project planning and is generally developed as part of the system architecting process after the system concept is defined. User requirements are decomposed into system requirements, which in turn are logically decomposed and allocated to a physical architecture. As soon as a concept of the system and the project exist, an initial WBS should be created. This initial WBS is the foundation for the initial project plan (or cost estimate) and reflects preliminary system concepts. Thus, as the system and approach to accomplishing the work evolve during the project, the WBS must also evolve both in structure and depth

Typically, the first WBS appears during the development of the proposal seeking approval or award of the development effort. This WBS organizes the response to the Request for Proposal (or other request) by serving as a compliance matrix that ties all the requirements (system and contractual) from the request to the response. This WBS organizes responsibility for developing the cost and schedule for each of the elements within the WBS. It should be referenced to the technical proposal to ensure that all work required is estimated. Often, this first WBS may be little more than a template derived from similar development projects.

The initial proposed WBS may be modified based on changes during the start up of the project. As the system design is baselined during the Preliminary Design Review (or equivalent project lifecycle control gate), the WBS should reflect all envisioned system components, as well as the high-level product realization (make-buy-reuse) and integration strategies for those components.

In a traditional, top-down development program, such as those implementing a “waterfall” or “vee” technical development strategy, the WBS will be a detailed reflection of the early design decisions that are typical in those programs/projects. Because of the extensive requirements elicitation, decomposition, and allocation done in those system development efforts, the WBS will usually be very detailed and reflect well-defined tasks early in the project.

In contrast to top-down development efforts, incremental or evolutionary programs often practice incremental planning, where the level of granularity in the WBS is progressively elaborated as each set of detailed design decisions are made. Each planning wave will document planned outcomes/deliverables with increasing detail. Similarly, the tasks associated with those deliverables will become more defined as the project proceeds through its development lifecycle. Thus, successive iterations of the WBS will change as the project evolves.

WBS Stakeholders

Nearly everyone interested in project performance becomes a stakeholder for the WBS, since it provides the structure for all project management and reporting. Customers typically negotiate or specify the reporting they want against the WBS. Furthermore, the definition of Control Accounts against WBS elements defines the assignment of performance for technical schedule and cost to the technical team. The project manager and organizational management will examine the WBS elements to determine sources of problems and to identify corrective action. Schedulers, cost estimators, finance, and program control personnel use the WBS to develop the schedules, project estimates, and earned value baselines and analysis.

As with all other areas of the project, the project manager has responsibility for creation of a viable WBS. Most of the WBS, however, reflects the system under development and the organizations responsible for the creation of the system. This makes the system component developers from all engineering disciplines responsible for defining the detailed technical activities of the WBS. Similarly, procurement, manufacturing and support functions may be involved in defining elements. In all cases the systems engineering team must be involved in defining the overall system architecture and integration strategy that define the structure of the WBS.

Tailoring the WBS

Most organizations have a preferred or "standard" approach to the WBS. This will reflect the nature of the industry, the customers and the performing organization. Tailoring is simply customizing the WBS to meet the needs of a specific project. Given that a typical—and our recommended—WBS uses a product-based structure that reflects the decomposition of the system, the first tailoring steps might be the inclusion of a non-product elements, such as a time-, funding-, or functionally-based elements (e.g., Systems Engineering). This may be necessary to accurately capture project costs that are not necessarily tied to any particular product element, or to meet the specific needs of stakeholder groups, such as funds management or organizational leadership.

Detailed tailoring may also occur within specific WBS elements. This may be driven by the use of subcontracts, risks, unique elements in the organization, or other factors such as an Integrated Product Team structure.

We occasionally hear criticisms of the "traditional WBS approach" to systems development by proponents of agile development methods who derisively refer to any top-down development approach as a "big design up-front" technique. We are not referring here to some agile enthusiasts who really do not understand the rigor inherent in all the various agile development methods, but those serious software engineers who argue that it is simply not possible to develop complex, software-intensive systems using top down-approaches. We counter that the WBS is a useful artifact with as much applicability to an agile development approach as with any traditional top-down development strategy.

Loosely defined, agile methods are a group of software development methodologies characterized by:

- *Individuals and interactions over processes and tools.*
- *Working software over comprehensive documentation.*
- *Customer collaboration over contract negotiation.*
- *Responding to change over following a plan.*

(Manifesto for Agile Software Development, www.agileAlliance.org)

At the risk of over-simplification, most agile methods entail collecting user requirements as user "stories;" prioritizing those requirements; allocating an achievable set of prioritized requirements to a pre-defined build cycle lasting anywhere from one week to one month; demonstrating working software to the users at the end of a build cycle to collect feedback and gather additional requirements; then repeating this process as many times as necessary until all user requirements are met—or the development team runs out of money. (Figure 7)

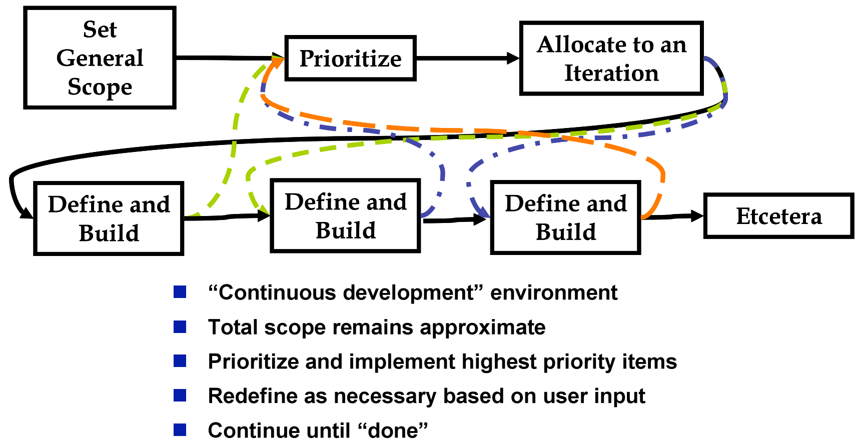

Figure 7. Generic Agile Development Cycle

Our perspective is that the WBS is the key artifact used to control product development. Whether one documents outcomes as features, user stories, software builds, or decomposed product elements, every successful project manager must have some framework for defining outcomes, controlling development activities, monitoring development progress, and accounting for the cost of development. We suggest that framework is the WBS.

Assessing WBS Quality

Given the exact same development project, different project teams may develop entirely different Work Breakdown Structures. This should not come as any surprise, because each project team will be a unique collection of people, and the plans they develop will reflect their collective expertise, creativity, experience, and understanding of the work required for a given system of interest. The WBS reflects the intersection of the project scope with the specific plan to accomplish it, and those plans will be a unique reflection of the teams that develop them. Therefore, it is difficult to define a single set of criteria that defines a "good" WBS. There are, however, some principles that will improve the usefulness of a WBS. The WBS should:

- ✓ List all components of the physical architecture for the system of interest.
  - This will include all system hardware, software, documentation, training, and other key system pieces.
- ✓ Illustrate how the components of the physical architecture will be integrated at successive levels of system decomposition.
- ✓ Link the project (and product) scope to the individuals responsible for performance.
  - Those individuals may be control account managers at higher levels of decomposition and individual contributors at lower levels of system decomposition.
- ✓ List all the work required to accomplish the project to the level of fidelity appropriate to the manager or individual assigned responsibility for achievement of a defined result.
  - The project manager and lead systems engineer have overall responsibility for the project; therefore, it is expected that their view of the WBS will have more breadth and less depth than the WBS view of a specific Subassembly Manager.
- ✓ Provide adequate insight to permit identification of problem sources (risk) and to implement appropriate corrective action to address those problems.

Obviously, there can be many different Work Breakdown Structures that satisfy these criteria for any specific project. Thus, the project leadership team must ultimately decide whether a given WBS provides them sufficient insight and perspective to successfully manage their project.

Decisions Enabled or Documented by the WBS

As we have discussed in this paper, the WBS is the fundamental tool for the organization and integration of the system's products and all associated efforts to build them. Each element of the WBS establishes a logical point to integrate technical requirements with cost and schedule. This integration provides the fundamental basis necessary for trade-off analyses both between and within system elements. It also provides the insight necessary for the project manager and systems engineering team to make work assignments to organizations and individuals and monitor technical progress.

The WBS is the artifact that ties together project scope, risk, schedule, and resources into a coherent systems management framework. Because the top level of the WBS (the PBS) reflects the system's physical architecture and illustrates the architect's integration strategy, then in effect, the WBS becomes the basis for many decisions regarding schedule, risks, and resources, to include the Physical Architecture Design approval, the Product Integration Strategy, IMS approval, and project resource allocations.

Similarly, the WBS is key to evaluating any changes to the project. Each of these decisions (e.g., appropriate Corrective Actions based on Technical Progress Assessment – EVM) requires evaluating the technical impact in the context of the cost, schedule, and risk, and a first step in these types of decisions is to identify the WBS elements affected by the potential change. Each of these WBS elements must then be evaluated as part of the decision process to ensure the impacts are acceptable to the overall system.

Many troubled projects achieve that dubious distinction because of weak configuration management leading to insufficient baseline control. An important aspect of an effective configuration management process is the ability to thoroughly evaluate the impact of changes. Well-conducted trade studies balance impacts to technical performance, schedule, cost, and risk to ensure that decisions optimize desired outcomes. By its very nature, this process must be linked to the affected WBS elements to assure all impacts are adequately considered. When confronted with the need to change some element of the system, each WBS manager must evaluate the change in terms of the impact on the schedule, cost, and risk to their element (including all dependencies) to ensure the result of the change continues to produce an acceptable outcome. Once a change decision is made, mapping to the WBS becomes the basis for the implementation of the change.

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BIOGRAPHY

Mark A. Wilson is CEO of Strategy Bridge International, Inc., a company that helps clients to bridge the gap between strategy and results. In addition to his domain expertise in national security space programs, he has broad experience in corporate-level strategy and policy formulation, business development, program execution, and fiscal management. A skilled facilitator and recognized expert in collaborative decision-making techniques, he has taught hundreds of hours of classroom instruction in Systems Engineering, Project Management, Quality Management, Risk Management, Integrated Product Teams, and Decision-Making. He is a Certified Systems Engineering Professional (INCOSE), Certified Manager of Quality/Organizational Excellence (American Society for Quality) and earned a B.S. from the U.S. Naval Academy and M.S. from the U.S. Naval Postgraduate School.

Frederick J. Manzer is Director of Project Management at Strategy Bridge International, Inc. A polished instructor and course developer for systems engineering and project management courses, he has successfully delivered hundreds of classes and provided tailored program support for major U.S. Defense contractors and US Government agencies acquiring major systems. As a nationally recognized expert in project planning and earned value, Mr. Manzer's systems engineering approach to project management facilitates acceptance by the engineering community and promotes successful implementation of recommended practices. He is a Project Management Professional (Project Management Institute) and earned a B.S. from the University of Maine and M.S. from the University of Arkansas.