# Design Maturity Model

Donald Przebowski
*Decisive Analytics*

*Until the invention of the Design Maturity Model (DMM), no existing models or procedures automatically linked and integrated the industry standards associated with metrics measurements, ISO 9000, and organizational responsibilities. Existing procedures had to be enhanced, not replaced, for the industry to accept the DMM. Cost for implementing the DMM had to be minimal, the DMM had to improve organizational discipline, and it had to facilitate development control. The final objective was to submit the DMM to a reputable organization for review and possible implementation.*

## Analyses of the Current Procedures

The initial analysis revealed that the software industry emphasizes metrics measurements to control software development. The Software Engineering Institute Capability Maturity Model (CMM), the Navy's Practical Software Measurements (PSM), the Army's Metrics Measurements, and recently ISO 9000 have evolved into industry standards. In general terms, ISO 9000 standards stress management and organizational responsibility and quality control. The standards are intentionally vague to permit organizations the freedom to create effective management policies. Eventually, it became clear that ISO 9000 standards can and should be reconciled to metrics measurements. The metrics measurements may be categorized into documentation control and performance measurement.

The metrics measurements used for documentation control are requirements traceability and design stability. Ordinarily, there are five main documents used to control software development. They are the requirements (the shall statements in the Statement of Work [SOW]), the specifications (design requirements), the functional description (the expanded requirements and the functions the system is expected to produce for the customer), the system interfaces (interactions between subsystems and systems), and the test requirements (test scenarios) to validate the system. The performance measurement standards are

- Breadth of Test – measuring the requirements tested, passed testing, and failed testing.
- Depth of Test – measuring the number of paths and conditions tested, passed testing, and failed testing.
- Complexity – measuring the degree of complexity, e.g., the number of lines of code.
- Computer Resources – measuring the storage capacity used by the system.
- System Response Time – measuring the time required for the system to respond to various actions.
- Defects/Faults – measuring the number of errors detected during testing.
- Lines of Code – measuring productivity, size, and complexity.
- Earned Value – measuring the variances associated with cost and schedule.

Insofar as documentation control, the analysis revealed that there was a misunderstanding of each type of document and purpose. For example, if one requested the SOW, one could be given the functional description or even the specifications. If one approached a tester for the SOW, one could be given the test document. Although this misinterpretation does not appear serious, an effective organization requires that every member understand the documentation if that member is expected to contribute to documentation control.

The analysis of performance measurement techniques revealed additional concerns. For example, during testing, the tester focused only on the test requirements document. If there was a design change in the requirements or the specifications that was not incorporated into the test requirements document, the tester would be unaware of that design change and, undoubtedly, test to obsolete requirements. There was no mechanism that automatically linked each type of document or a document's paragraph to the design requirements or specifications of a software item: computer software unit (CSU), computer software component (CSC), or corresponding computer software configuration item (CSCI). In addition, for a specific CSU, the requirements paragraph could be labeled 1111; the functional description's paragraph 2222, etc. One should consider the overwhelming task of first finding the appropriate paragraph, then analyzing and reconciling the design requirements to the test requirements line by line or paragraph by paragraph when the system contains multiple CSUs and a million lines of code.

Additional analysis revealed that the software organizations, especially contracts, focused on delivering a specific end item, often defined by a contract line item number (CLIN), and a corresponding CSCI, CSC, or CSU. An organization, such as test engineering, only considered the particular CSU, CSC, and CSCI being tested. There was little consideration of the value of automatically linking the CLIN to the CSU, CSC, or CSCI to the documentation status and the performance measurements to facilitate management control.

The additional issue identified by the analysis was related to identifying organizational responsibility, e.g., design engineering, by CSU, CSC, or CSCI. The main purpose of performance measurement techniques, such as breadth of test (testing the requirements), is to provide organization members and management the status and potential problems to enable project management to facilitate and assign corrective action to each organization. For example, if testing is behind schedule for a CSU, the project manager must be alerted, who then determines the reason and prepares to assign corrective action to the testers and other relevant organizations.

Essentially, the analyses revealed that the documentation control and performance measurements of the CMM and the PSM were effective except for the following shortcomings: There was no method to identify each type of document and no mechanism to link the CLIN, documentation, performance measurement, and organizational responsibility by CSU, CSC, and CSCI. These shortcomings led to the creation of the DMM.

## Design Maturity Model

The DMM resides in EXCEL and provides a framework to prevent loss of control during software development. The DMM enhances the software industry's approach to control software development by using the features of a Product Work Breakdown Structure (PWBS) as a mechanism to integrate and link the documentation, performance measurements, and organizational responsibilities. This analytical approach should enhance organizational effectiveness, facilitate corrective action, and increase the probability of project success. A management control document (MCD) is designed as the primary configuration control mechanism to monitor the documentation status. The initial step is to define the PWBS and link the CSUs, CSCs, and CSCIs to each PWBS element. The next step is to define and link the corresponding documentation. Once the data is entered into the MCD, it can be automatically transmitted to the appropriate performance measurement spreadsheets. In addition, a PWBS/organizational matrix is designed to identify organizational responsibilities for the total system, the CSU, the CSC, and the CSCI. A PWBS/organizational matrix serves as a link to a contractor's accounting system, which is the official financial status of a project and is essential to determine profit and loss.

## Project Inception

Documentation control must begin at project inception. During project inception, the customer's and the contractor's most challenging task is to adequately define and document the requirements and expand and flow those requirements into the specifications, functional description, system interfaces, and test requirements. Unfortunately, the software complexity often prevents stabilizing the requirements during this early phase. This instability of the requirements or design forces most contractors to continuously refine the requirements and to build the software incrementally—which is referred to as evolutionary acquisition or incremental builds. As the project evolves, the design matures and documentation control requires measuring the design changes imposed upon the baseline and ensuring that the changes are incorporated or flowed into all the documents. Evolutionary acquisition enforces the idea of the increased discipline inherent in the DMM. The CSUs, CSCs, and CSCIs are linked to the documentation, performance measurements, and organizational responsibility to prevent loss of control as the design matures. The problem of controlling what is being built and linking it to the documentation and performance measurement and who is responsible for building the product surfaced in the 1970s because various contractors failed to fulfill technical and cost objectives. In response to this problem, the Department of Defense (DoD) created a control system: A PWBS defined what was to be built and linked the PWBS to documentation and performance measurements. An organizational matrix linked the PWBS to the organizations or who was responsible for building the product. The PWBS system has proven invaluable as a mechanism to monitor and control technical performance, cost, and schedule.

## Product Work Breakdown Structure

Since its creation, the DoD and contractors have successfully used the PWBS system to define and monitor aircraft configurations and to link the corresponding requirements and specifications to the system, subsystem, elements, and organizational responsibilities. Most contractors establish an MCD similar to that shown in Figure 1. It identifies the PWBS for the total system as 1000. PWBS 1000 is level 1 as noted by the arrow in the illustration. The description for level 1 is the total system; the total system name is the Weapon System. The SOW paragraph is 1000. PWBS 1000, level 1 includes level 2: 1100 and 1600. Level 2 includes level 3: PWBS 1100 includes 1110, and PWBS 1600 includes 1610, 1620, 1630, and 1640. Level 3, PWBS 1110, includes level 4: 1111, 1112, 1113, 1114, and 1115. In this example, there is no level 4 for 1600. One point is worth noting: PWBS 1600 is defined as management activities for the entire system and ordinarily is not assigned to any particular PWBS. Each PWBS is assigned a specific SOW paragraph, e.g., PWBS 1111 corresponds to the requirements paragraph 1111. Thus, in clear terms, the system design is defined, and a new PWBS or paragraph may be inserted into the system to accommodate design changes, and it is easy to link the project's documentation and performance measurement techniques to a specific PWBS. However, for software acquisition, the MCD should be more extensive.

## Management Control Document Software

The first step toward establishing the DMM's process or model is to assign the CLIN and the PWBS along with its description. The PWBS identifies the configuration or product design by

Figure 1. *Management control document.*

| PWBS LEVEL | & L | Hardware Level | PWBS Description | Requirements Paragraph |
|---|---|---|---|---|
| 1000 | 1 | Total System | Weapon System (WS) | 1000 |
| 1100 | 2 | System 'A' | Mission Objectives (MO) | 1100 |
| 1110 | 3 | Subsystem | Engineering Objectives (EO) | 1110 |
| 1111 | 4 | Element 1 | System Architecture (SA) | 1111 |
| 1112 | 4 | Element 2 | Subsystem Architecture (SSA) | 1112 |
| 1113 | 4 | Element 3 | System Interfaces (SI) | 1113 |
| 1114 | 4 | Element 4 | Legacy Systems (LS) | 1114 |
| 1115 | 4 | Element 5 | Reuse/COTS (RC) | 1115 |
| | | | | |
| 1600 | 2 | | Management | 1600 |
| 1610 | 3 | | Program Management | 1610 |
| 1620 | 3 | | Financial Management | 1620 |
| 1630 | 3 | | CSCI Manager | 1630 |
| 1640 | 3 | | Project Support | 1640 |

software levels: CSU, CSC, or CSCI. The PWBS data is entered into the MCD. The MCD acts as the primary configuration control mechanism. The second step consists of defining the documentation by PWBS and entering that data into the MCD. Documentation control should be concerned with monitoring and controlling the baseline and the effect a change in one document may have upon another: A change in requirements may affect the specifications and the functional description. To enhance organizational communication and mitigate any confusion between documents, a unique letter identifies each type of document: 'R' for the requirements, 'S' for the specifications, 'F' for the functional description, 'N' for the system interfaces, and 'T' for the test requirements. The MCD data are automatically transmitted or mapped to the performance measurements, and a change entered into the MCD will be automatically reflected on every performance measurement spreadsheet. The MCD enhances ISO 9000 standards. The PWBS enhances management control by identifying the current design and the product(s) to be delivered to the customer, which addresses ISO 9000's management responsibility. In addition to identifying the current design or product, the MCD provides the means to monitor and control the documentation that reconciles ISO 9000's product identification and traceability, design control and documentation, and data control. An example follows, which includes solving the problem of evolutionary acquisition or incremental builds.

Figure 2 reflects DMM's MCD. A CLIN and a PWBS for the software levels CSCI, CSC, and CSU, along with a description, is assigned. Each type of document paragraph is identified with a unique letter, and the paragraph number is identical to the PWBS. The 'In' column is used to designate the baseline or incremental build. The baseline is initialized to '0'; each increment is indexed. The 'CH' column is used to designate design changes imposed upon the baseline (core system) or an incremental build. Figure 2 represents a theoretical weapon system. For this example, an incremental build is assigned to PWBS R1112, level 4. In addition, for PWBS R1111, the 'CH' column reflects that there is a change in requirements imposed upon the basic system: The

Figure 2. *Management control document data.*

Management Control Document Data

Contract Line Item Number (CLIN) = 0001

ISO 9000: Management Responsibility, Design Control, Documentation and Data Control and Product Identification and Traceability

Requirements: Reqts — System Interface: SI
Specifications: Sp — Test Plan: TR
Functional Description: FD

Baseline = 0, Design Changes = Number > 0 — Increment (In No.) or Build Number = Number > 0

Baseline — Increment No. 1 — Design Change

| PWBS | LEVEL | Software Level S/W Lev | PWBS Descr. | Req'ts Para. 'R' | Baseline or Incr. No In No. | Ch # | Sp Para. 'S' | Ch # | FD Para. 'F' | Ch # | SI Para. 'N' | Ch # | TR Para. 'T' | Ch # |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1000 | 1 | Sys | WS | R1000 | 0 | 0 | S1000 | 0 | F1000 | 0 | N1000 | 0 | T1000 | 0 |
| 1100 | 2 | CSCI | MO | R1100 | 0 | 0 | S1100 | 0 | F1100 | 0 | N1100 | 0 | T1100 | 0 |
| 1110 | 3 | CSC | EO | R1110 | 0 | 0 | S1110 | 0 | F1110 | 0 | N1110 | 0 | T1110 | 0 |
| 1111 | 4 | CSU | SA | R1111 | 0 | 1 | S1111 | 0 | F1111 | 0 | N1111 | 0 | T1111 | 0 |
| 1112 | 4 | CSU | SSA | R1112 | 1 | 0 | S1112 | 0 | F1112 | 0 | N1112 | 0 | T1112 | 0 |
| 1113 | 4 | CSU | SIA | R1113 | 0 | 0 | S1113 | 0 | F1113 | 0 | N1113 | 0 | T1113 | 0 |
| 1114 | 4 | CSU | LS | R1114 | 0 | 0 | S1114 | 0 | F1114 | 0 | N1114 | 0 | T1114 | 0 |
| 1115 | 4 | CSU | RC | R1115 | 0 | 0 | S1115 | 0 | F1115 | 0 | N1115 | 0 | T1115 | 0 |

'CH' column is '1.' In other words, PWBS R1111's requirements have been reviewed, but the specifications, test requirements, etc., have not been reviewed: The 'CH' columns remain '0.' Upon reviewing the MCD spreadsheet, any organizational member would be alerted that there was a change in the requirements paragraph R1111, but the change has not been incorporated into the remaining documents. This DMM procedure would ensure an activity such as testing would be implemented based upon the current documentation and configuration. In general terms, the appropriate contractor's organization—usually the Change Board members—would review, reject, or approve the design changes that affect the basic system or the incremental builds and would be required to update the configuration and documentation status. The same principles used in the MCD, related to documentation control, may be applied to a performance measurement such as breadth of test.

## Breadth of Test (BOT)

The performance measurement BOT measures the requirements that have been tested, passed testing, and failed testing. Figure 3 demonstrates how DMM's BOT would be used in a contractor's environment. The ISO 9000 quality standards are, essentially, related to testing. In addition, since the documentation status is reflected on the spreadsheet, the BOT spreadsheet reconciles ISO 9000's Design Control, Documentation & Data Control, Product Identification and Traceability, and Inspection and Testing, which are inherent in monitoring test status. The documentation status, e.g., requirements, are automatically transmitted from the MCD to the BOT measurement spreadsheet. The MCD generates the identical documentation status to all the performance measurements mentioned previously, such as depth of test, computer resources, and complexity. The example includes identifying the CLIN and demonstrates, by PWBS, the status of the documentation to ensure that a tester may verify that testing will be based upon the correct configuration. The 'In' column is maintained to identify the baseline, and the 'CH' column accommodates design changes. The number of requirements tested, passed testing, and failed testing or defects/faults are included in the example. There are 500 total requirements (PWBS R1000). Of those, 375 have passed testing and 125 failed, or there are 125 defects. The 'In' column for R1112 contains a '1,' which indicates an incremental build, and there is a change in requirements for PWBS R1111 (the 'CH' column is 1), but the remaining documentation, in particular the test plan for PWBS T1111, reflects '0' in the 'CH' column. This implies the responsible organization, usually the change board, has failed to review the test plan for PWBS 1111.

## PWBS/Organizational Matrix

The PWBS/organizational matrix permits management to measure organizational performance. The PWBS system was designed to provide a mechanism to roll up the design status and the performance measurement values to each higher level: Level 1 includes level 2, etc. This roll-up feature permits project management the freedom to measure progress at any level: the

Breadth of Test — Data as of MM,DD,YY

Contract Line Item Number (CLIN) = 0001

ISO 9000 Quality System, Design Control, Documentation & Data Control, Inspection & Testing

Requirements: Reqts — System Interface: SI
Specifications: Sp — Test Plan: TR
Functional Description: FD

Td: Tested. P Tg: Passed Testing. F Tg: Failed Testing

Baseline = 0, Design Changes = Number > 0 — Increment (In No.) or Build Number = Number > 0

Baseline — Increment No. 1 — Design Change

| PWBS LEVEL | | S/w Level | PWBS DS | Reqts Para R' | In # | Ch # | Sp Para S' | Ch # | FD Para F' | Ch # | SI Para N' | Ch # | TR Para T' | Ch # | Breadth of Test Requirements Testing Td | P Tg | F Tg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 0 0 0 | 1 | Sys | WS | R1000 | 0 | 0 | S1000 | 0 | F1000 | 0 | N1000 | 0 | T1000 | 0 | 500 | 375 | 125 |
| 1 1 0 0 | 2 | CSCI | MO | R1100 | 0 | 0 | S1100 | 0 | F1100 | 0 | N1100 | 0 | T1100 | 0 | 500 | 375 | 125 |
| 1 1 1 0 | 3 | CSC | EO | R1110 | 0 | 0 | S1110 | 0 | F1110 | 0 | N1110 | 0 | T1110 | 0 | 500 | 375 | 125 |
| 1 1 1 1 | 4 | CSU | SA | R1111 | 0 | 1 | S1111 | 0 | F1111 | 0 | N1111 | 0 | T1111 | 0 | 100 | 75 | 25 |
| 1 1 1 2 | 4 | CSU | SSA | R1112 | 1 | 0 | S1112 | 0 | F1112 | 0 | N1112 | 0 | T1112 | 0 | 100 | 75 | 25 |
| 1 1 1 3 | 4 | CSU | SIA | R1113 | 0 | 0 | S1113 | 0 | F1113 | 0 | N1113 | 0 | T1113 | 0 | 100 | 75 | 25 |
| 1 1 1 4 | 4 | CSU | LS | R1114 | 0 | 0 | S1114 | 0 | F1114 | 0 | N1114 | 0 | T1114 | 0 | 100 | 75 | 25 |
| 1 1 1 5 | 4 | CSU | RC | R1115 | 0 | 0 | S1115 | 0 | F1115 | 0 | N1115 | 0 | T1115 | 0 | 100 | 75 | 25 |

Figure 3. *Breadth of test.*

total system, CSCI, CSC, and CSU. ISO 9000 Management Responsibilities are assigned to PWBS 1600, usually an industry standard for management. Ordinarily, management activities are not allocated to any specific PWBS, but rather to management of the entire system. The PWBS/organizational matrix (Figure 4) represents a theoretical weapon system and defines the PWBS level, CSCI, etc., and assigns an organizational letter, a departmental number, which is the link to the accounting system, and the accounting name of each department. The PWBS/organizational matrix is the essential link from the PWBS to the PWBS descriptions to the organizations responsible for producing the product and to the accounting system. In the example, the organizational responsibilities are reconciled to each PWBS. For example, the program manager, 'a,' is assigned to PWBS 1610, the financial manager, 'b,' to 1620, etc. The PWBS 1600, as well as PWBS 1100, are rolled up to level 1: PWBS 1000.

Essentially, the PWBS/organizational matrix is a valuable tool or report to facilitate management control and define organizational responsibility and authority through all organizational levels. It also serves as the link to audit contract status by organization. Once the metrics measurements and other relevant performance data are identified by PWBS, the project manager can

Figure 4. *PWBS/organizational matrix.*

PWBS/Organizational Matrix
ISO 9000 Management Responsibility
(Organizational Responsibility)

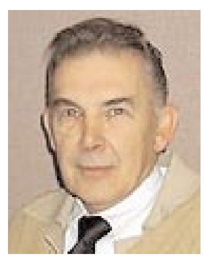
| PWBS LEVEL | S/w Level | PWBS Description | Organizations a b c d e f g h i j k l m n | Accounting Dept. No. | Department Name | ORG |
|---|---|---|---|---|---|---|
| 1 0 0 0 1 | System | Weapon System | | 100 | Project Manager | a |
| 1 1 0 0 2 | CSCI | Mission Objectives | c d e f h i | 110 | Financial Manager | b |
| 1 1 1 0 3 | CSC | Engineering Objectives | c d e f h | 120 | Design Engineering | c |
| 1 1 1 1 4 | CSU | System Architecture | c d e f h | 130 | Sys. Engr. & Integration | d |
| 1 1 1 2 4 | CSU | Subsystem Architecture | c d e f h | 140 | Test Engineering | e |
| 1 1 1 3 4 | CSU | System Interface Architecture | c d e f h | 150 | Programming | f |
| 1 1 1 4 4 | CSU | Legacy Systems | c d e f h | 160 | Testers | g |
| 1 1 1 5 4 | CSU | Reuse, COTS | c d e f h | 170 | Database | h |
| 1 6 0 0 2 | | Management | | 180 | CSCI Manager | I |
| 1 6 1 0 3 | | Program Management | a | 190 | Metrics | j |
| 1 6 2 0 3 | | Financial Management | b | 200 | Configuration Mgmt | k |
| 1 6 3 0 3 | | CSCI Manager | I | 210 | Data Management | l |
| 1 6 4 0 3 | | Project Support | j k l m n | 220 | Scheduling | m |
| | | | | 230 | Product Assurance | n |

determine what organizations are assigned to each PWBS and use that information to validate responsibilities and assign the required corrective action. In addition, since the PWBS, the level, and the description are automatically generated by the MCD, the PWBS/organizational matrix will reflect the current design status or configuration.

## Conclusion

Documentation control and performance measurement techniques already are industry standards. Since the DMM will enhance those standards, it should be acceptable to the industry, and there should be little incremental cost to implement the model. DMM simplifies the integration of ISO 9000 standards and improves organizational discipline and documentation control. The DMM may be used by any contractor or customer (DoD or NASA) to enhance and facilitate software development controls. The implementation of the DMM will decrease the cost of software development by reducing the time spent by organizations dedicated to documentation control, reviewing the design status, and ensuring that activities are focused on the correct design and documentation. There are additional savings associated with the increased communication between the contractor and the customer using the MCD, performance measurement data, and the PWBS/organizational matrix. The DMM has been given to the Goddard Space Flight Center through the technology transfer program for possible implementation and to the Langley Research Center and the Kennedy Space Center for review. ◆

## About the Author



Donald Przebowski is employed by Decisive Analytics as a senior cost analyst and technical writer and participates in the technical and cost evaluations that pertain to National Missile Defense. He also creates procedures and models that will facilitate the control of software development. Employed by Fairchild Republic for about 22 years, he managed software systems development, parametric estimating, performance measurement, statistics, and major proposals and was a project and business manager on a major subsystem. He joined the Grumman Corporation in 1987 to support the NASA Space Station Freedom Program, where he developed independent cost assessments for hardware and software and evaluated the impact of various design changes. He participated in the evaluation of Boeing, McDonnell Douglas, and Rocketdyne's management policies. He was employed by the Statistic Corporation on a software development project, where he applied performance measurement techniques to measure project status.

Decisive Analytics
1235 Jefferson Davis Highway, Suite 400
Arlington, VA 22202
Voice: 703-414-5032
Fax: 703-414-5066
E-mail: djp@decisive-analytics.com