Using Earned Value to Track Requirement Progress

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Abstract. It is necessary to track the status of each requirement as it moves through engineering life cycle activities. Measures that reflect the status of the requirements are essential to monitor program status and serve as a scorecard to indicate that requirements are being implemented on schedule.

This paper provides guidance to use the tools of requirements traceability to plan and measure the progress of the requirements management activities. The requirements traceability matrix (RTM) can be used as a scheduling source and as a set of base measures of Earned Value (EV). Finally, the importance and value of comparing the schedule variances of the requirements management and tracing activities with the variances of other project activities is discussed.

Meeting Product Requirements

Progress. It is important to quantify the progression of requirements from concept to formulation to design to test. Peter Baxter discusses assessing these requirements to ensure that your product contains all required functionality. Baxter's advice addresses software requirements but is also applicable to the system requirements:

It is advisable to measure the number of requirements that each software process generates or accepts. Measure the number of system or top-level software requirements (i.e. features or capabilities), as well as the decomposition of system requirements into more detailed requirements. In order to track differences between developed and planned requirements, it is necessary to also measure the status of each requirement as it moves through life cycle activities. A typical requirement status could be: defined, approved, allocated, designed, implemented, tested, and verified. A measure that shows the status of all requirements is essential in monitoring program status and acts as a scorecard to illustrate that requirements are being implemented. Early in the program schedule, ensure that requirements become defined, approved, and allocated as the system architecture is finalized. Near the end of the program schedule, you should see requirements move from implemented status, to tested, then to verified status (Baxter 2002).

Measuring the status of each requirement as it moves through life cycle activities is an essential control tool for effective project management.

Requirements Status

Baxter recommended a set of requirements statuses:

- Defined
- Approved
- Allocated
- Designed

- Implemented
- Tested
- Verified

Early Validation

Three other requirements management activities should be added to that list. The first is early validation of the requirement. Validation is a process for confirming that the requirements are implemented in the delivered system. As used here, ensure that the requirement is a real requirement (a requirement necessary to meet the real customer and user needs); that the requirement meets the criteria of a good requirement; and that the rationale (why the requirement is needed) for having the requirement in order to meet the minimum customer and user needs has been assessed (Young 2001). Requirements validation is critical to successful system product development and implementation. In other words, requirements are validated when it is certain that the subject set of requirements describes the input requirements and objectives and the resulting system products satisfy the requirements and objectives.

Leaving validation until the end of the project severely increases the risk of failure. Validation activities early in the project can reduce that risk. Early requirements validation should be completed before requirements approval. This process will reduce the possibility of the wrong product being designed and implemented. Typical early requirements validation activities include:

- Analyze each requirement to ensure that it is unambiguous, testable, and verifiable.
- Ensure that the set of defined acquirer requirements agrees with acquirer needs and expectations.
- Analyze and compare identified and collected acquirer requirements to the set of defined acquirer requirements to determine downward traceability.
- Analyze and compare the set of defined acquirer requirements to the identified and collected acquirer requirements to determine upward traceability.
- Record validation results in the information database.

The Systems and Software Productivity Consortium (SSPC) has provided the following discussion of ways to accomplish early validation (SSPC 2006).

- Inspection
  Focused on meeting particular customer constraints.
  For example: An inspection of a machine to see that it will fit in the desired space or an inspection of code modules to ensure their compliance with maintenance demands.

- Demonstration
  Having the customer or a representative use the product to ensure it meets some minimum constraints (i.e., usability). Also can be used to perform some acceptance tests where the product is running in the intended environment versus some test or development lab.

For example: Having pilots fly an aircraft before the customer signs off on the program.

- Analysis
  Using some form of analysis to validate that the product will perform as needed when demonstrating it is too costly, unsafe, or generally impractical.
  For example: Using interpolation of performance load based on the worst case that is feasible to generate, to validate a need that is more stringent than this worst case. If it can be shown that there is no scaling problem, this would be sufficient to validate the performance need.

- Prior data
  When a component being used has been already validated for a previous project that had similar or stricter constraints.
  For example: Using a well-known encryption component to meet security needs when the component has been already validated for tougher security requirements.

Select a Verification Method for Each Requirement

A second additional recommended requirements management activity is the selection of the verification method. Verification is a process for ensuring that the design solution satisfies the requirements. This should also occur before approval of the requirements to ensure that the approved verification method is included in the verification document or detailed test procedure.

Trace the Requirement to the Verification Document

The third recommended requirements management activity is tracing the requirement to the verification document. Traceability of the requirement to the detailed test procedure ensures that necessary tests of the requirements will be included in the test procedure.

Revised/Recommended Requirements Statuses

To recap, a recommended set of requirements management statuses is:

- Defined
- Validated
- Verification method determined
- Approved
- Allocated
- Traced to verification document (test procedure)
- Designed
- Implemented
- Tested
- Verified

Discrete Measurement of Requirements Management and Tracing

When constructing a project plan, project managers (PM) often fail to establish milestones and discrete, objective measures of progress for those activities that deal with requirements development, management and tracing. They use several rationales for concluding that these activities should be Level of Effort (LOE). However, if the PM has decided to apply EV to requirements development because of the assessed risk, than discrete EV techniques should and can be implemented.

Let's call the people that are responsible for documenting the requirements management and tracing activities requirements engineers. Requirements engineers say that the major work products of requirements management and tracing activities are the database, the RTM, and associated documents. For example, the associated documents may contain the requirements, the test procedures, and evidence of verifying the requirements.

When determining which project activities and work products should be discretely scheduled and tracked, PMs regard the RTM as a tool, not as a work product. They propose that populating the RTM with data is a support activity to the real work products of engineering development (designs, test articles, test results etc.). They also argue that the actual completion of many of activities listed above, as well as the associated documents, is the responsibility of other engineers, not the requirements management engineers. They then point to those who are actually doing the designing or testing or making related decisions. Consequently, the requirements engineers conclude that, if the allocated requirements have not been implemented into the design on schedule, or the test procedure does not yet include all necessary test cases, or the verification of requirements is behind schedule, it's not their fault. Therefore, they propose, their activities should be measured as LOE.

It is recommended that, regardless of accountability, the progress of requirements, as they progress through the engineering life cycle, should be scheduled and measured against a plan. Of course, discrete earned value techniques should be used for management control. Even though the budget for the requirements engineers may be relatively small, as compared with the budgets for all other engineers, the earned value taken in control accounts or work packages for requirements management activities can be the most important indicator of project schedule performance. The schedule status of the set of requirements reveals more about the health of the project than any other schedule performance indicator in the Performance Measurement Baseline (PMB).

For example, if we are behind schedule in evolving the real requirements, gaining approval of the requirements by the joint (customer and developer) team, allocating the requirements to components of the system, meeting requirements in the system design, accomplishing testing of requirements, or validating the requirements, subsequent activities should not start.

Use the RTM to Develop the Plan

Develop an RTM planning and status report that is organized according to the project's information needs. The requirements may be organized according to the Work Breakdown Structure (WBS), the functional architecture, the design architecture, or by the key documents that contain the requirements and will be approved by the customer. For each row of the RTM, show the total number of requirements.

After the planned number of requirements has been established for each component in the RTM, develop a time-phased schedule for the planned completion of each requirements management activity. For example, specify the planned completion of the following activities for each requirement:

- Define
- Validate (Valid.)
- Determine verification method (Verif. Meth.)
- Allocate (Alloc)
- Trace to verification document (Verif. Doc.)
- Verify

If less measurement granularity is sufficient, than specify the planned completion of each requirement activity for the set of requirements at each component level.

Summarize the planned completion data by reporting period. This will later be used to compute the time-phased budgeted cost for work scheduled (BCWS).

How to Measure Progress

The measure of progress is objectively determined based on the number of completed requirements activities. It is compared with the number of activities that were planned to be completed at that time. That will enable the RTM to provide more than requirements traceability and status. It will be the source of schedule progress measures for EV.

How to Determine EV

When a component has many requirements, each requirement may receive an equal distribution of the total budget or may receive a weighted allocation, depending on its relative estimated effort or business value. In other words, some requirements may be more difficult to address and therefore worth more than others for the purpose of EV.

RTM Example

The following example includes a series of tables that demonstrate how to plan, status, and analyze schedule variances of requirements management activities. In this example, the requirements are organized according to the design architecture. For a sample project, the architecture is comprised of five components:

- Enclosure
- Radio transmitter
- Battery
- Control

- Software

Each component goes through six requirements management activities. Table 1 shows the components, the number of requirements per component, the total budget for the requirements (reqs.) management work package, and the allocation of budget to the six activities. For this example, assume that each requirement has equal budget value. Normally, the budget value will be proportional to the relative effort to accomplish the activities.

SE Budget	No. Reqs	SE Budget	Define	Valid	Verif. Meth	Alloc	Verif. Doc	Verify
Budget %			**15%**	**15%**	**15%**	**20%**	**15%**	**20%**
Component								
Enclosure	**3**	**240**	**36**	**36**	**36**	**48**	**36**	**48**
Transmitter	**1**	**80**	**12**	**12**	**12**	**16**	**12**	**16**
Battery	**2**	**160**	**24**	**24**	**24**	**32**	**24**	**32**
Control	**1**	**80**	**12**	**12**	**12**	**16**	**12**	**16**
Software	**9**	**720**	**108**	**108**	**108**	**144**	**108**	**144**
Total	**16**	**1280**	**192**	**192**	**192**	**256**	**192**	**256**

Table 1 Budget allocation

Table 2 contains the schedule and the Budgeted Cost of Work Scheduled (BCWS) for completion of the requirements management activities for one of the components, the Enclosure. The time-phased BCWS is determined by allocating the budget for each activity to the month in which it is scheduled.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Total	
Enclosure										
Schedule										
Defined			3							
Validated				2	1					
Verification Method					1	2				
Allocated							3			
Traced to Verif. Doc.								3		
Verified									3	
	Budget/									
BCWS current	**Activity**									
Defined	**12**		**36**							**36**
Validated	**12**			**24**	**12**					**36**
Verification Method	**12**				**12**	**24**				**36**
Allocated	**16**						**48**			**48**
Traced to Verif. Doc.	**12**							**36**		**36**
Verified	**16**								**48**	**48**
Total			**36**	**24**	**24**	**24**	**48**	**36**	**48**	**240**
BCWS cumulative			**36**	**60**	**84**	**108**	**156**	**192**	**240**	

Table 2 Requirements Management Engineering Schedule and BCWS

Table 3 shows the both the number of Enclosure requirements management activities that were completed, the EV performance, also called the Budgeted Cost of Work Performed (BCWP), and the schedule variance.

		Jan	Feb	Mar	Apr	May
Enclosure						
Completed	**Budget/Activity**					
Defined	**12**			**3**		
Validated	**12**				**1**	**1**
Verif. Method	**12**				**1**	
BCWP cumulative		**0**	**36**	**36**	**60**	**72**
BCWS cumulative		**36**	**60**	**84**	**108**	**156**
Schedule Variance		**-36**	**-24**	**-48**	**-48**	**-84**

Table 3 EV Performance

As of the end of May, the schedule variance is –84. It is comprised of two validation activities (-24), two verification method activities (-24), and three validation activities (-36).

Total Requirements Management EV

Although Tables 2 and 3 above illustrate just the Enclosure, the source of earned value would be the statused RTM that shows all five components and sixteen requirements. The RTM can easily be used to determine the number or percent complete of all requirements management

activities and the resultant earned value.

Reasonableness Check

When the schedule variance of the requirements management activities is compared with that of the remainder of the project, or when similar subsets are compared, we would expect that they would show a similar story. It would be hard to imagine a scenario where the requirements management activities are significantly behind schedule and other engineering activities are not significantly behind.

So, the earned value of the requirements management organization can be the leading performance indicator for the remainder of the project. We recommend that the project manager compare the relative progress of the requirements management organization with that of other engineering activities as a reasonableness or sanity check.

If the requirements management organization's work package is behind schedule, then the related development activities of other engineering organizations should also be behind schedule. If related activities do not show similar progress, review and revise the base measures of their respective work packages to ensure that they contain consistent milestones and completion criteria with regard to the product requirements.

(Solomon 2006) provides guidance for requirements-based planning and for specifying effective measures of technical progress for all engineering organizations using the principles of Performance-Based Earned Value.

Conclusions

If the requirements management and traceability activities are behind schedule, it is an early warning that the rest of the project is or will be in trouble. We recommend that a PM look at the progress and schedule variance of these activities early in any review.

The requirements management and traceability activities should be discretely planned and measured. If these activities are realistically planned, they provide a valid basis for Performance-Based Earned Value and give the PM incite into progress of the total program.

References

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