# Benchmarking Functional Verification

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## INTRODUCTION

This article describes "asureMark™ " - the Functional verification Capability Maturity Model (FV-CMM™) benchmarking process developed by TVS to help the user measure the maturity of their verification processes and to provide a framework for planning improvements.

When describing any activity it is important to clearly define its purpose. In this case we needed to understand how our customers benefit from applying benchmarking:

1. The constant increase in complexity of electronics means that functional verification faces an ever growing challenge. Hence it is essential not only to consider today's challenges but anticipate the future. Companies that are often in crisis because their management has been effectively ambushed by this constant march of verification complexity. Companies therefore need a process that can give them a clear warning before things go wrong!

2. Functional verification requires a vast amount of resources of all kinds: people, machines and EDA licenses. Even more importantly it has a major impact on project timescales. Yet often engineers and management in companies have very different perceptions of current capabilities and fail to identify or address key areas of weakness.

3. A process of continuous improvement needs a shared 'language' and framework that can be used to identify issues, then define, prioritize and monitor tasks. This is a key requirement for companies to ensure they will continue to be able to meet future verification challenges.

Over the years there have been numerous attempts to develop benchmarking methodologies. One of the most widely used is the Capability Maturity Model (CMMI) developed by the Software Engineering Institute at Carnegie Mellon University. Although aimed at software engineering it provides a framework that is widely applicable to most business activities. However, whilst we have drawn considerable inspiration from CMMI, it has a number of serious limitations when trying to use it to benchmark a highly specific activity such as functional verification:

> The FV-CMM™ is a framework for benchmarking functional verification capability which provides:
> - An integrated view of the organization from the viewpoint of functional verification
> - An objective benchmark for measuring the maturity of functional verification activities
> - A framework for process improvement that can help management define goals and priorities

1. The CMMI is relatively abstract and does not address domain specific 'capabilities', yet these are at the heart of effective functional verification[1]
2. Deploying CMMI is actually quite an involved process that takes considerable time and expertise. Even reading the specification is quite a lengthy commitment. Our experience suggested that this would be a major barrier to adoption.
3. Function actually follows form. The capabilities of teams are largely shaped by their organization and practices. Imposing a rigid benchmarking process can over time distort an organization and prevent necessary change. Hence any benchmarking process needed to be flexible in order to meet the current and future needs of different companies.

Much the same observations have been made independently by other industry experts (Foster & Warner, 6/2009). For the above reasons we aimed to develop a more specific, but flexible and light-weight process dedicated to benchmarking functional verification. The FV-CMM™ is a framework that provides a light weight solution for benchmarking functional verification capability which can provide:

- An integrated view of the organization from the viewpoint of functional verification
- An objective benchmark for measuring the maturity of functional verification activities

- A framework for process improvement that can help management define goals and priorities

Whilst it has some similarities to the 'Evolving Capabilities Model' Foster and Warner proposed it has a unique approach to decomposing capability in a 'top down' fashion and then evaluating maturity 'bottom up'. The rest of this article describes the three key elements of this benchmarking process: capability, maturity and the actual benchmarking process that TVS adopts.

## CAPABILITY

The FV-CMM™ benchmark has a hierarchical structure that starts by breaking capability down into key process areas such as 'functional verification planning and scenario creation'. These can be customized for each client as a company developing interface IP will face different challenges to one developing CPUs or doing SoC integration. The process areas may also change over time as companies evolve and technology continues to develop. The only requirement is that each should have a clearly defined purpose and a clear impact on functional verification. We have so far defined 13 possible process areas ranging from 'metrics, coverage and closure' through 'specification and design' to 'organizational capability'.

Each process area consists of a set of specific goals (e.g. 'ensure the integrity of the code base') and practices (e.g. 'all tasks should have an agreed completion date') that capture key requirements. For example in the case of 'specification and design' the specific goals and practices for functional verification are:

- Give the verification team visibility of the architecture and micro-architecture corner cases
- Make the design 'verification friendly'
- Make the design stable to ensure verification isn't trying to hit a moving target

These in turn are broken down into example actions and activities that address that issue. These are not intended to be exhaustive but do serve to connect the abstract framework to concrete actions. For example design stability includes 'checking whether the project enforces a process of successively freezing the RTL'. This structure can easily be customized to the specific needs of different application domains, different design styles or different companies.

## MATURITY

When evaluating maturity we consider three aspects:

***Ownership:*** this can vary from tasks, tools and expertise being specific to named individuals to ownership being shared across the project or the entire company wide community. This corresponds to the level at which: adoption has occurred, decisions are made, or support can sensibly be requested. This also reflects the process for continuous improvement that can vary from best practice being owned by individuals who implement improvements in an ad hoc fashion to institutionalized fact based learning.

***Visibility:*** this can vary from undocumented, with no external input, to living documentation with quantitative metrics and full involvement of the stakeholders. It involves the following three key aspects: the availability of documentation, the use of metrics for measuring progress and quality, and the use of reviews.

***Execution:*** this can vary from ad hoc and incomplete to a repeatable process supporting fact based continuous improvement. Typical characteristics of a repeatable process are documentation and automation.

The maturity of each aspect is defined as being at one of five possible levels. Each of these levels corresponds to a clear step in maturity. These are:

***Initial:*** Processes are typically ad hoc and applied incompletely or on a best effort basis, especially in times of crisis. Goals are often not satisfied. Processes are typically not documented or otherwise made repeatable and best practice remains in the ownership of individuals rather than being captured by the organization. Verification planning is either not performed or is performed and not documented, or plans are incomplete and not maintained once written. Stakeholders are not normally involved in the planning.

***Managed:*** The processes are performed consistently and the goals are satisfied. Processes are owned and aligned at project level. They are automated, or otherwise repeatable, and will serve to locally capture best practice. However there are few specific checks on the capabilities of tools and processes. Initial verification planning is performed and documented but the plans are not maintained. Metrics are used to demonstrate progress (scenario completion, code coverage, bug rate) but not to check that the plan has been implemented. The status of the work is only visible to management at defined points and the predictability of verification completion is weak.

***Defined (also known as ´Planned'):*** The processes are planned in conjunction with the relevant stakeholders. Implementation is adequately resourced. The verification plan is either maintained over the life of the project or is a living plan. In either case there are checks or coverage metrics allowing the results to be monitored and reviewed. The capability of specific processes and tools is reviewed qualitatively to ensure good alignment with tasks. The predictability of verification completion is strong. Best practice is consistently shared across projects.

***Quantitatively Managed:*** Using metrics and profiling. Living documentation ensures full visibility at all times and ensures the widest possible involvement of stakeholders in the verification process.

***Optimizing:*** The organization practices fact based learning and continuous improvement at an institutional level using data collected across the organization and projects. Quantitative metrics are used for both coverage closure and continuous improvement of product, tools, process and organization.

Table 1 below details how the five maturity levels map onto three aspects of ownership, visibility and execution

Process maturity is not a substitute for skilled and dedicated Engineers but it will make the work of those individuals more predictable and repeatable, and make it easier for the organization to learn from best practice.

## PROCESS

Evaluation against the FV-CMM™ benchmark proceeds 'bottom up' using the example actions and activities to

***Table 1: Maturity levels for the three key aspects***

| | Initial | Managed | Defined | Quantitative | Optimising |
|---|---|---|---|---|---|
| Ownership | Individual | A Project Team. Normally belonging to one group and located on a single site. | Project Stakeholders, possibly spread across different groups and sites, or ad hoc groups of projects | A community, normally spread across multiple sites, independent of any specific project. (Participation is normally voluntary.) | Company wide or institutionalised. Part of the formal processes and organisation defined by the company. (Participation is normally compulsory.) |
| Visibility | Undocumented. No reviews. No metrics. | Documents incomplete or unmaintained. Progress metrics defined.<br>Point reviews (typically at alpha, beta and first release). | Maintained docs. Regular tracking against progress metrics and at least basic quality metrics. | Living docs. Continuous tracking against progress metrics and quantified quality metrics. | A consistent view of all projects. Data, including progress metrics and quantified quality metrics, integrated across the organisation. |
| Execution | Ad hoc | Tasks performed but completion not explicitly checked | Tasks planned and implemented in a systematic fashion. Check completion of planned tasks. | Quantifiable metrics used for coverage closure and release determinism | Quantifiable metrics used to drive continuous improvement. |

| Process | Ownership | Visibility | Execution |
|---|---|---|---|
| Maximise reuse of existing verification knowledge | Initial: Reliant on individuals bringing knowledge to project | Managed: Knowledge reused in verification plan but not maintained | Managed: Knowledge used in verification but no check that it is completed |
| Ensure customer use scenarios are considered in the verification plan | Defined: All stakeholders involved in defining customer use scenarios | Managed: Tests defined for customer use scenarios but not maintained | Adhoc: No explicit tracking to ensure that |

***Table 2: Example application of FV-CMM™ to UVM adoption***

structure evidence gathering. This typically takes the form of in depth interviews with key project or department staff including verification managers, design managers and project managers as well as key verification experts. This may be backed up by reviewing project documents and data but it differs in subtle ways from an audit. Here the intention is to facilitate discovery and draw out the collective knowledge of the team rather than enforce practices. The observations are recorded and validated by being fed back for comment to the interviewees and other relevant staff. The reviewers then use their expertise and this evidence to 'score' the maturity of each of the three key aspects of ownership, visibility and execution for the associated goal or practice. Overall maturity is then evaluated based on the maturity of the three component aspects. Rather than impose an arbitrary algorithm we make this a subjective process, the only restriction being that the overall rating can't exceed the range set by the individual aspects, hence three wrongs can't make a right! The results for the individual goals or practices are in turn are used to guide the overall evaluation of each process area. All these results are captured in a single easily accessible spread sheet and can be made even more visible through the use of spider graphs to present the key results. Sometimes there is a mismatch in perception between various team members, or between engineers and management. This can be identified by following a 360 feedback process where staff, as well as the reviewers, score the maturity of the different process areas.

Whilst this evaluation is partially subjective the evidence based 'bottom up' flow aims to ensure the conclusions are fact based. By defining target maturity levels appropriate to the business and its future product roadmap a gap analysis can be conducted. The results can then be used to identify key issues and plan improvements in either specific processes or in overall functional verification maturity. Regular reviews against this model can ensure the organization maintains an appropriate level or help drive a process of continuous improvement, though subsequent audits should aim to apply common standards for evaluating maturity.

## ASUREMARK™ IN ACTION: APPLYING FV-CMM™ TO UVM ADOPTION

TVS is not able to talk in detail about the application of FV-CMM™ with customers. Instead, this paper will discuss how it is applied to a company considering adoption of UVM [2] (the Universal Verification Methodology). UVM is being developed within Accellera's Verification Intellectual Property Technical Subcommittee[3] and is supported by Mentor Grtableaphics, Cadence and Synopsys. It is gaining rapid widespread adoption within the verification community but, in the experience of TVS, mere adoption of a constrained random methodology such as UVM will not necessarily lead to verification improvements. The FV-CMM™ benchmarking process will enable a company to understand better it's readiness for the adoption of UVM.

For example, 'functional verification planning and scenario creation' is an important process area within constrained random verification. This process has a number of goals such as 'Ensure the widest possible input into verification planning' and 'Make verification plan and its scenarios visible' which break down into practices. The table above considers two of the practises that contribute the first of these two goals.

We have found that the output of the benchmarking process is best presented as a spider diagram such as the one shown in Figure 1 on the following page. The figure shows three assessments: internal, external and a target assessment. Having an internal and external assessment captures the differences in perceptions between the internal

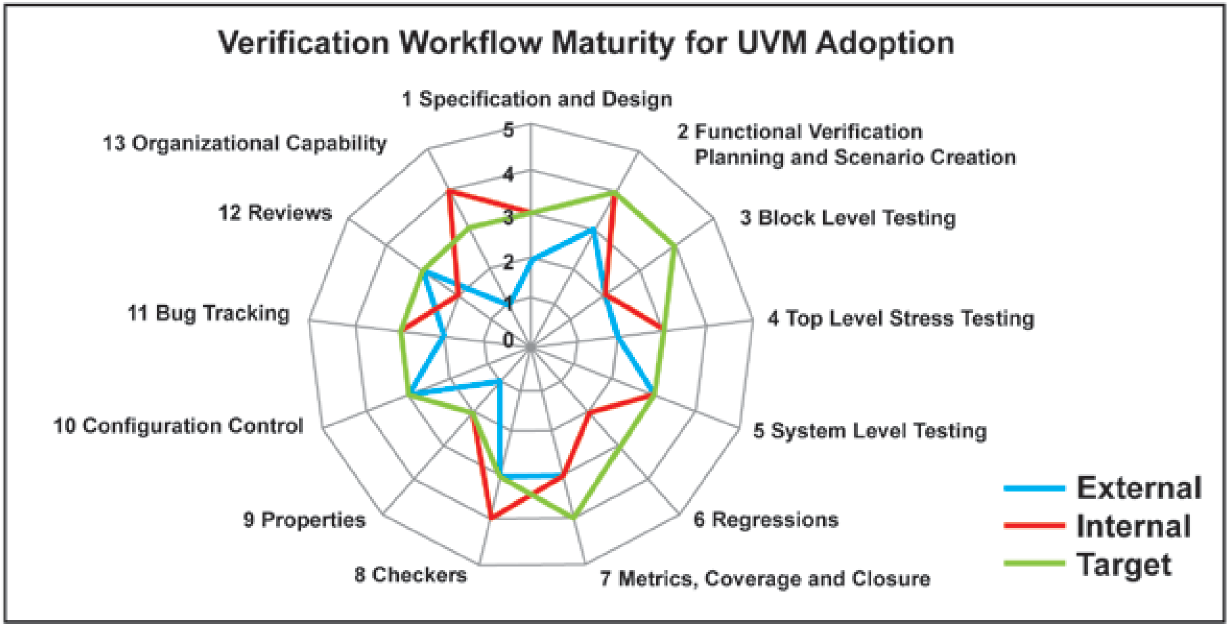


***Figure 1: Spider diagram for verification maturity***

team and the external TVS consultants which can lead to very valuable discussions. Finally, the target assessment allows for improvement plans to be defined in terms of the goals and practises required in order to maximise the benefits of UVM adoption.

## SUMMARY

The FV-CMM™ is a flexible, light-weight benchmarking process specifically targeting functional verification. This avoids some key limitations of a more general framework such as CMMI.

Capability is captured top down by identifying process areas which are then decomposed into goals and practices that can then be linked to example actions and activities that connect the benchmarking process to concrete actions.

Evaluation then proceeds bottom up by considering ownership, visibility and execution. Maturity is rated using five clearly distinct levels from 'ad hoc' to 'Optimizing'.

Doing a gap analysis against the business requirements helps TVS' customers identify weak areas of their verification process in a timely fashion and the FV-CMM™ also provides a framework for planning improvements.

## WORKS CITED

Foster, H., & Warner, M. (6/2009). Evolving Verification Capabilities. Verification Horizons.

## NOTES

[1] For this reason software testing has developed the domain specific ´Test Maturity Model Integration' (TMMi)

[2] See http://www.uvmworld.org/

[3] See http://www.accellera.org/activities/vip

## ABOUT THE AUTHORS

Mike Bartley and Mike Benjamin have over 35 years of hardware verification between them gained at STMicroelectronics, Infineon and start-up fabless companies. They have both worked as verification engineers, team leaders, led central functional teams and worked as consultants advising on company-wide verification strategy. They have experience in verifying blocks, CPUs, systems and SoC's and have applied various techniques and tools including formal, constrained random, assertion-based, OVM, testbench qualification, etc.

Both authors work with TVS, an independent hardware verification consultancy that provides both high-level consultancy on verification strategy and verification execution resources in several locations around the world (www.tandvsolns.co.uk).