WHITEPAPER

Manage End-to-End Quality of Complex Software Systems

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Management summary

End-to-end quality management, employing the lessons learned in the field of independent verification and validation (IV&V), is a series of technical, managerial and sometimes financial activities, performed by a team of specialists that is independent from the core project team, to ensure:

- Achievement of the desired level of quality for all relevant project results, including a fully functional IT system over its entire lifetime
- Full transparency concerning the state of the project, particularly with regard to product risks
- Unbiased analyses of underlying project processes and software products
- Early error detection and correction of anomalies early in the lifecycle resulting in higher efficiency
- Enhanced management insight into risks associated with these processes and products

Common practice in the implementation of major software projects without IV&V services has revealed that many organisations did not have the necessary and sufficient means for quality management and thus had to rely on the respective contractor's activities. These were usually focused on testing only of key functionalities, while disregarding other vital lifetime aspects such as integration, performance, maintainability or portability. This lack of independent 360-degree end-to-end quality management seriously endangers the operability and future viability of such software systems.

Thus, taking into consideration the extra costs of such services for the added value listed above, end-to-end quality management is in general an investment that counts. Several studies have produced evidence that end-to-end quality management delivered as IV&V has yielded a positive return on investment for organisations, varying from factors of 1.5 up to 12 in relation to the expenditure on IV&V activities [1].

End-to-end quality management services are highly project- and context-specific. Depending on the subsequent operational risk of a given software system and the corresponding quality requirements, the effort will scale both in scope and time.

Introduction

Current IT-systems are characterised by a high technological complexity, a wide range of different technologies, an increasing mix of legacy, re-use and open source systems as well as new developments.

Additionally systems in many industries aim for long runtimes, sometimes dictated by integration with physical systems and sometimes desired to ensure a positive return on substantial IT investments. At the same time, a permanently changing world around these systems and ever shorter market cycles increase the challenges of delivering suitable systems that are able to satisfy these requirements.

In large organisations, IT systems are typically not developed in-house but are rather procured from third party suppliers. These procuring organisations specialise in running the resulting programs and projects and are not necessarily geared up to provide the knowledge and manpower to successfully manage the procurement of complex IT systems. The main focus is on just meeting the functional requirements and budget ceilings while attaching little importance to other aspects such as non-functional requirements and operational costs in the in-service phase, which have proven to be two thirds of the total lifecycle costs.

In addition, procuring organisations tend to place a strong focus on their core business and thus show little interest in checking the quality of delivered systems themselves. A consequence may be that the contractor will not only deliver the system or software, but also specifications and tests. Such a procurement strategy involves substantial risks, endangering successful operations during the in-service phase and seriously affecting operating budgets.

Recent innovations such as agile, lean or DevOps approaches do not offer an adequate solution to the underlying problems. Without an independent function focused on the quality of the delivered goods, the customer will be completely at the contractor's mercy, potentially implying substantial risks for both the project and the in-service phase.

Experience has shown that such a function needs to be established from the very beginning, i.e. the definition of business requirements, and that it needs to be in place to supervise not just the IT project. After final system acceptance it is also good practice to have IV&V services for the maintenance phases, as typically, changes will again be delivered by external contractors.

The following chapters outline a proven approach and strategy to enable procuring organisations to successfully manage and oversee the quality of commissioned IT projects.

Market – current status and outlook

End-to-end quality management is most often found in large organisations which source IT solutions solely or mainly from external suppliers and do not rely on internal software development capabilities. The North Atlantic Treaty Organization (NATO) is a good example in that it runs large-scale technology projects, aims to implement both IT and military hardware and procures these projects from commercial suppliers.

In such constellations, agile approaches have not yet reached the critical mass that they have achieved elsewhere. Subsequently, the software lifecycle relies on a flow of activities – first on the contractor side and then with the purchasing organisation. Experience from failed projects in the 90s and 00s has led to a trend by purchasers to employ end-to-end quality management in order to minimise the risk of encountering major quality (verification) or scope (validation) issues late in the project at which point it has been found extremely difficult to recover from such issues.

In the market, end-to-end quality management is only partly conducted by purchasers themselves and is heavily supported by contracting out independent verification and validation (IV&V) services from third party providers. This also ensures resilience against peaks and troughs in demand – third party providers can support delivery of end-to-end quality management in times of high demand while an internal core team ensures the availability of expertise and continuity in times of low demand.

Other industries are catching on to this concept. In particular, industrial and logistics companies increasingly run similar types of projects with a mix of hardware and heavily interlinked IT components (cf. the German Industry 4.0 initiative), for instance intelligent plants, warehouses or container terminals. In addition, large-scale IT programs in government and public administration are often accompanied by IV&V services. Sometimes an IV&V approach has an additional cost-controlling component, which provides program management with sound information about project cost development.

SQS end-to-end quality management for large-scale public sector projects

In this section we will outline how SQS' end-to-end quality management services were used to successfully support a series of large-scale projects in the public and defence sectors. In these sectors, the end-to-end quality management was delivered through commitments as IV&V functions to the purchasing agencies.

Approach to end-to-end quality

An expedient approach to mastering the challenge of end-to-end quality management is to engage an independent authority to verify and validate an IT project from concept to decommissioning, as with continuous integration build control. In scope are the four principal dimensions based on which projects succeed or fail ("the four Ps"): People, Processes, Products, Projects [2]. As a consequence, an end-to-end QM approach needs to cover these dimensions.

IEEE Std. 1012:1998 [3] defines independence in IV&V using three different parameters: technical independence, managerial independence and financial independence.

- Technical independence is achieved by IV&V specialists who use their own expertise to assess development processes and products independently of the developers.
- Managerial independence requires an IV&V team that is organisationally separate from the organisation responsible for the system implementation. The IV&V specialists independently select the software artefacts to be analysed and tested. They select the appropriate IV&V techniques, define the schedule of IV&V activities and select the specific technical issues and problems to address.
- Financial independence means that the IV&V services are sponsored by a budget that is administered independently of the development organisation.

In any case, the inter-relationship between purchaser, IV&V services provider and contractor, as well as the activities focusing on quality, need to be governed by an overarching framework (Figure 1) This framework will essentially comprise a quality dimension, an artefact dimension and an organisational dimension. In this respect, it is important that independent IV&V services are incorporated into the procurement contract between purchaser and contractor.

The quality dimension will focus mainly on system requirements, software code and architecture, as well as the test approach and products. This dimension will be covered in more detail in the following chapters.

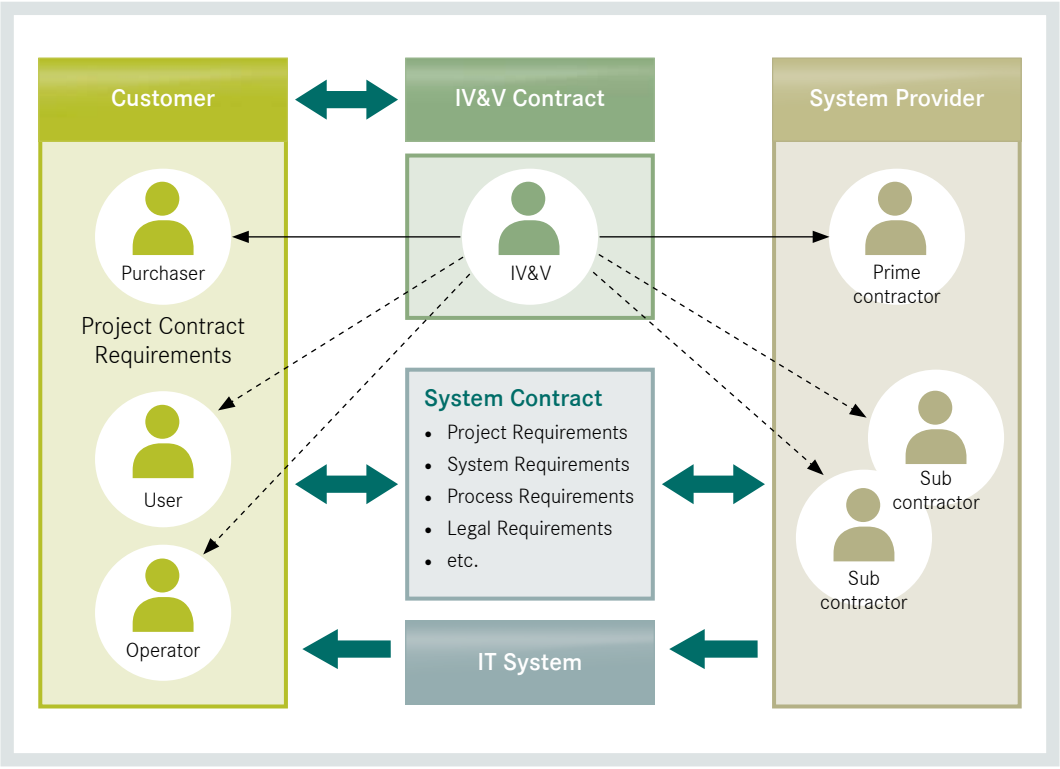

Figure 1: Relationship of purchaser, contractor and the independent verification and validation services as a third party

A powerful end-to-end quality approach during project support will focus mainly on two aspects. The project-independent view of the IV&V team shall check whether the essential project-related risks have been identified and whether such risks are being managed appropriately. Are these risks considered adequately in further project progressions? Does this relate particularly to risks which are bound up with software and project products? Are all relevant lifecycle products considered such as specifications, source code, testing artefacts, and user- or operations manuals, etc.? In this context it is also important to determine whether relevant provisions have been made in the development project for the requirements of the software maintenance phase.

The artefacts to be focused on by the IV&V effort depend on the quality model defined for a given system or software project. If, for example, the future maintainability and expandability of the software is a key issue, a sophisticated IV&V approach should address the provisions that have been made within the project for a corresponding architecture and maintainable source code.

The organisational dimension establishes the relations of the IV&V team with regard to the purchaser and contractor, and defines the terms of reference of the IV&V team. It should also establish a process framework which sets out the management of requirements and the software test activities.

Making quality controllable

The definition of activities subsumed under end-to-end quality management or IV&V is rather broad, including both technical and management activities. Relevant standards have been published e.g. by the European Space Agency [4] or IEEE Standard 1012-19981. Both standards describe software IV&V processes that help to determine whether the development and testing products of a given activity conform to the requirements of that activity. In order to be fully effective, IV&V effort should be made early in the project lifecycle and should performed in parallel with software development, not after software development is complete. The standards also address validation and its specific roles and activities, as this provides information about whether the software satisfies the intended use and the operator's needs. Typical activities for a sound IV&V approach include assessments, analysis, evaluation, reviews, inspection and testing of software products and processes. It is recommended that software be assessed in the context of the later system, including the full operational environment with all hardware components and interfaces.

To establish an effective IV&V approach in critical IT infrastructures, several requirements need to be fulfilled. Firstly, it is desirable for an organisation acquiring complex IT systems to support the procurement process with a sound Software Lifecycle Framework, which provides a well-defined framework for the implementation of IT programs and software projects. Based on available international standards such as ISO/IEC 12207 [5} or ISO/IEC 15288 [6], often in such lifecycle architectures all fundamental parameters for procurement processes are clearly set out, such as the responsibilities of purchaser and contractor. Furthermore, in addition to the description of all relevant project processes, clear demands for software development should be made. And lastly, just as decisive for project success are a well-organised requirements management structure and an all-encompassing test strategy that clearly defines which products should grow out of test projects, to what extent and at what quality level.

The IV&V project also needs to be clearly defined, with its impact on the project development and system integration clearly and contractually agreed, generally based on a partnership executed in parallel to the actual development contract (Figure 2).

Depending on the demand resulting either from the project-related risk or the disposable budget, IV&V may follow one of two different basic strategies. Either IV&V services are executed continuously in a standalone project running parallel, or alternatively IV&V may also be executed in relation to milestones, where the IV&V team takes action only at specified landmarks by analysing and assessing key products and processes.

In both cases, appropriate quality probes are used to determine whether the project approach is risk-adequate and whether the built products meet the agreed quality goals.

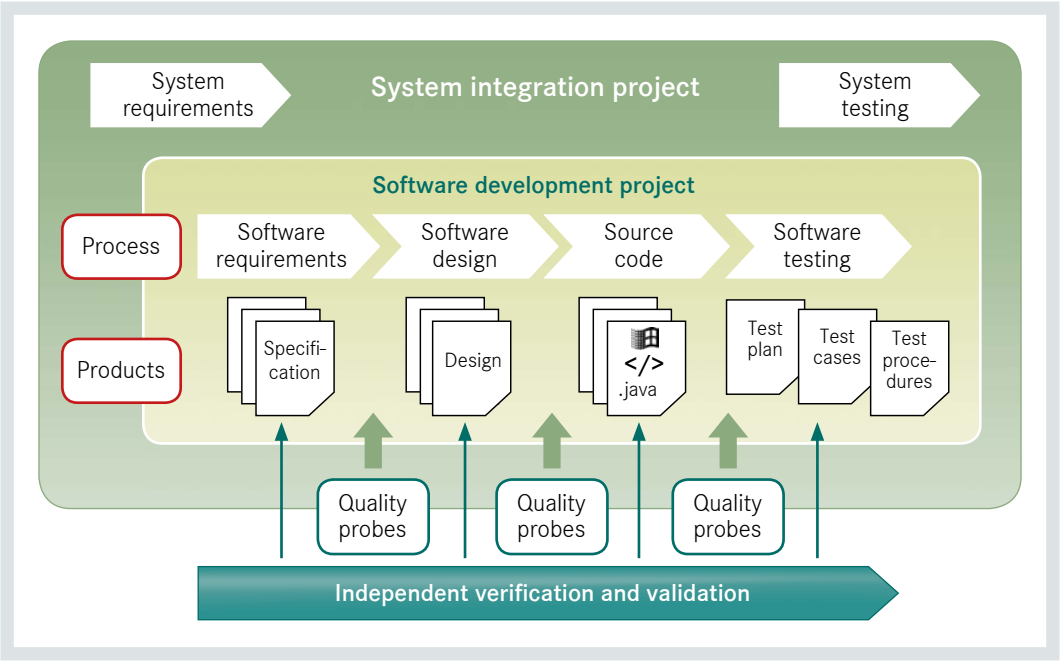

Figure 2: IV&V uses quality probes to establish whether risk and quality in the software project are under control

Effective IV&V usually addresses three main focal areas for each project:

- Quality and traceability of requirements
- Consistency of implementation with stated requirements
- Adequacy of the testing approach to its artefacts and products

Particularly in large-scale procurement projects with a highly complex supply chain consisting of prime contractor and multiple 2nd tier subcontractors, the traceability between functional and non-functional requirements and their consistent treatment in subsequent project phases is of crucial importance for project success. For instance, the overall sustainability of an IT system requires consistency between the implementation and the related design documentation – meaning that checks ensuring this consistency based on code and architecture need to be conducted as part of an IV&V process.

If the creation of a long-lived software system falls within the project's scope, and if that software system is expected to be adapted to a regularly changing environment, then the project requirements concerning maintainability are of paramount importance to its viability during the in-service phase (cf. ISO/IEC 25010) [7]. Thorough IV&V verifies which non-functional requirements have been specified in relation to this quality attribute (maintainability) and which measures the contractors have taken to satisfy these requirements.

Figure 3: Tool and method portfolio for a comprehensive IV&V approach

Finally, IV&V needs to evaluate whether the analytical approaches and methods used by the project's testing effort are suitable to provide full transparency of the system's quality status. In addition to this, dedicated independent checks set up by the IV&V team themselves act as quality probes to gain better visibility of crucial aspects of quality. Dedicated analyses of aspects such as code and architecture maintainability are a logical consequence in those cases where the evaluation of the respective project approach has already identified potential gaps.

A test project constitutes the central source of information for project management to understand the overall quality of a software system. Testing therefore has the objective of ensuring that the proper tests have been defined and executed to cover the quality attributes considered relevant. This is not restricted to functional suitability but covers all other non-functional quality attributes having a bearing on the operation of the software as well.

Making quality tangible

Due to the plethora of requirements, a comprehensive IV&V approach is based on having a multi-disciplinary team with many specialists to draw upon. Process and project management skills are required, as is extensive knowledge of requirements management, analysis of source code and architecture, and testing expertise. Figure 3 shows the core quality assurance methods that SQS draws upon in the delivery of IV&V projects.

In addition to these general skills, which are a prerequisite for staffing an efficient IV&V team, an IV&V project needs to be equipped with a basic toolset to manage all relevant IV&V data and identified risks. For this purpose, SQS uses the so-called Y-model [8] which links all relevant artefacts of the development project to quality attributes and quality indicators that can be analysed. This management tool can be easily adapted to generate decisive reports and management summaries and is – together with an informative and decisive risk register – part of the project management equipment for SQS IV&V teams. If source code analysis is also in the IV&V focus, additional tools are required. However, source code analysis is not just a matter of good analysis tools which are commercially available. SQS has, for example, a quality indicator collection of more than 100 single indicators for all common programming languages. In addition, we can make use of a huge Code Quality Management project database, which allows us to benchmark a system under investigation.

An important part of the IV&V process is independent testing. Many years of independent quality control have revealed that test cases for acceptance testing performed by contractors are often trivial or sometimes adapted to the as-built-situation instead of covering real requirements. It is therefore essential for the IV&V team not only to check the contractor-defined test cases but - all important - to define test cases applying specifically to identified risk areas and to execute independent tests. This will require the IV&V team to have access to the test environment, including appropriate tools. Again, this needs to be incorporated into the procurement contract.

Making quality transparent

As a key connector between project and line organisation, technology and business, purchaser and contractor, quality management becomes a key organisational enabler. Nowhere is this enablement more visible than in the reporting of quality management status and results. First and foremost, reporting ensures that the visibility and transparency gained through the end-to-end quality management becomes available to all relevant stakeholders. This not only means that the information is made available, but more importantly that it is provided in a format and with a level of detail appropriate for each stakeholder. A CEO or MD needs a different type of information than a project manager does.

Costs

Of course, Independent Verification and Validation will occasion additional costs, which can typically be estimated at 5 to 10% of the total costs of an IT project, depending on the complexity of the project and the investment in IV&V activities [9]. In light of typical cost overruns attributable to a lack of control over a large-scale program which can easily exceed 100% or even more of the original budget, this figure rightfully looks like the inexpensive insurance against unwelcome future surprises that it is.

Thus when imperative quality goals in complex and critical software components need to be met, the essential, subject-specific contribution to critical IT infrastructures of an effective IV&V approach should not be underestimated. Add to which, various studies dealing with the return on investment in IV&V reveal that the additional commitment to quality pays off in any case. Hunt [1] assumes a factor of 1.5 up to 12. The IT representative of Georgia calculates an annual benefit of several million US dollars for his organisation [10].

Conclusion & outlook

In short, our experience with delivering end-to-end QM and IV&V can be condensed into a few high level dos and don'ts which neatly summarise the more strategic aspects to be considered when performing such a function (Table 1).

Studies and manifold use cases have revealed that IV&V makes a considerable contribution to the successful implementation of complex IT and software projects. It is an excellent way to exercise 360° end-to-end quality control and ensure project success. It offers considerable support to the purchaser in getting the right system and ensuring this is properly built. It also contributes significantly to ensuring that the system is delivered on time and on budget.

Future IT and software systems will increase in complexity, with challenges in respect of portability, adaptability and maintainability. The relevant settings of course will need to be configured at the beginning of a project in the definition phase. Wide SQS experience has led to the conclusion that having IV&V services throughout the entire procurement phase and also in the in-service phase is essential for a project's success.

Do	Don't
Divide & Conquer Keep QM tasks and responsibilities separate from project teams to ensure independent views.	**Have unclear interfaces** Interfaces with contractors and their subcontractors are next to impossible to change once they have been established and contractually affirmed. These need to be right first time.
Be Proactive Set up QM early on in the lifecycle so that QM can ensure that "the right thing" is requested and that QM needs are reflected in contracts.	**Be late to the party** Establishing an end-to-end QM function late on is difficult, riddled with contractual issues and dependent on decisions made, and therefore far less effective.
Prioritise Clearly define what is important and what is not, from the top down to a granular level.	**Duplicate work** In a complex program organisation, QA and testing are conducted on many levels by different organisations. Aim not to repeat activities that have been conducted somewhere else already – rather use the time/effort to test at a higher level of integration.
Source Specialists Some of the tasks arising during the course of the QM effort will require specialist skills (such as evaluations of processes or technical quality). Ensure in advance that you have a way to source these specialists when you need them.	**Leave QM to your contractor** There are a whole range of reasons why the delivery of a system and the end-to-end QM should not be muddled together. Not least is that this creates inherent conflicts of interest, but also that only the procuring organisation can define what they consider acceptable quality and what they do not.

Table 1: Typical dos and don'ts

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