SPiCE for SPACE: A Process Assessment and Improvement Method for Space Software Development

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As part of an ESA-sponsored programme for software process improvement, a method for software process assessment has been developed that is conformant with the requirements of the international standard ISO/IEC TR 15504, commonly known as 'SPiCE'. An initiative of the Agency's Product Assurance and Safety Department, in co-operation with the Mathematics and Software Division, the 'SPiCE for SPACE' (S4S) method aims to encourage the production of the best possible software products and services within the European space industry.

Introduction

The S4S method includes an assessment model incorporating space software practices following ECSS (European Cooperation for Space Standardization) standard requirements for the production of space software, a documented approach and a software assessment tool, together with templates of key outputs that support the performance of S4S assessments. Four pilot assessments of space software projects were performed in late 1999 to validate the method, followed by a series of eight trial assessments in 2000 and 2001. In addition, a further programme of assessments encouraging the use of S4S over the next three years has already begun.

As part of the same contract, a method of software process improvement has been developed that provides the structure necessary for space-software organisations to make effective improvements based on the results of S4S assessments. Meanwhile, a new version of the S4S method called SPiCE for SPACE-Risk, or S4S-R, is being developed that will enable software suppliers to target those processes that lead to the highest risks and to make the most effective use of limited improvement resources.

By promoting the best-practice concepts of SPiCE and addressing the specific needs of space software, ESA expects S4S to emerge as the prevailing vehicle for process improvement within the European space-software industry.

The S4S method

Software process assessment is used to establish a baseline for an organisation's capability to develop quality software. As such, it is a critical part of the cycle of continuous process improvement. The in-depth knowledge provided by a process assessment may be used to identify improvements to the processes that an organisation applies to software development. In addition, the process models on which assessment methods are based provide examples of industry best practices integrated into the complete development process. Thus, it is desirable to provide space-software suppliers with a method to evaluate their processes in order to identify potential improvement needs within their organisations. The same assessment method may be used by space-software customers to evaluate the capabilities of current and potential suppliers. The method may also be used by suppliers to verify their compliance with ESA process requirements (ECSS).

The assessment model

In designing the S4S assessment model, the exemplary assessment model from ISO/IEC TR 15504 was taken as a reference. It was then tailored using both ECSS requirements on the production of space software, and software process models developed by ESA in previous study projects. ISO 15504 is an international standard for software process assessment.

The ISO 15504 model itself has two dimensions: process and capability. The process dimension consists of a comprehensive set of processes describing all activities in software development. The process dimension consists of forty software processes. These processes are closely mapped to the software lifecycle processes in ISO 12207 and cover all of the different activities that are involved in software development.

The processes are organised into five categories: Customer-Supplier, Engineering, Support, Management, and Organisation. These range in scope from customer-supplier processes like supplier selection, to engineering processes such as software design and management and organisation processes such as project management and human-resource management, respectively. Each ISO 15504 process has a defined purpose and set of outcomes that should result from performing the process. In addition, each process includes a list of base practices, actions that may be performed to achieve the process outcomes. Finally, input and output work products are defined for each process. Work products are the artefacts that are used, produced or transformed by the process, such as documents or code.

The capability dimension provides a six-level rating scheme against which each process is independently evaluated. Results range from 0 (Incomplete) to 5 (Optimising). The six capability levels are based on nine process attributes. In addition, the capability dimension contains management practices, indicators of capability for each level.

When performing an assessment, there is no mandatory set of processes that must be evaluated. Rather, the model offers a modular approach in which the organisation selects the processes to assess based on business goals.

ESA space systems must be developed according to the requirements published by the European Cooperation for Space Standardization (ECSS), which are to be applied in the management, engineering, and product assurance of space projects and applications. The standards are written in the form of requirements and expected outputs. All of the ECSS Level-1 standards were used as primary input in developing the S4S assessment model. Of particular importance were the two standards that focus on software: ECSS-E-40, 'Space Engineering – Software', and ECSS-Q-80, 'Space Product Assurance – Software Product Assurance'. In addition, several internal space-software process models derived from these standards were used to refine the S4S assessment model.

In forming the S4S process dimension, all processes and base practices were adopted 'as is' from the ISO 15504 assessment model in Part 5 of ISO 15504. Requirements from ECSS documents or activities from space-software process models were matched with assessment model processes and base practices. In addition, the process dimension was augmented with processes, base practices and notes created to reflect activities not present in ISO 15504-5. All of the exemplary model work products were either matched with the expected outputs of ECSS requirements or, where no match was found, were kept in S4S 'as is'. New work products and work-product characteristics were formed to represent ECSS outputs not covered by the exemplary model. These new processes and process indicators incorporate space-software needs into S4S. The common origin of ECSS-E-40 and ECSS-Q-80 (i.e. ISO 12207) made this tailoring approach feasible. Figure 1 indicates the relationship between S4S, ECSS-E-40, ECSS-Q-80, ISO 12207, and ISO 15504.

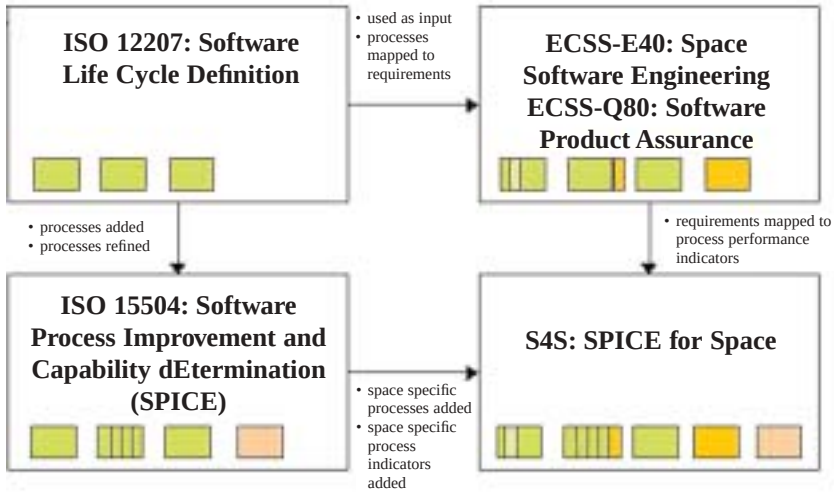


Figure 1. The relationship between S4S, ECSS-E-40, ECSS-Q-80, ISO 12207, and ISO 15504

As a result of these efforts, the process dimension of S4S has been considerably expanded from the exemplary model. Four new processes, about 50 base practices, and about 60 new notes have been added to reflect ECSS activities. The process dimension of the S4S model is shown in Figure 2. Processes new to the ISO 15504 model are shaded in light-grey, while processes with base practices added are represented in bold. Processes with notes added are underlined. Figure 2 shows clearly that enhancements have been made throughout the entire process dimension.

Of the four new processes, two extend the exemplary model to cover issues particular to

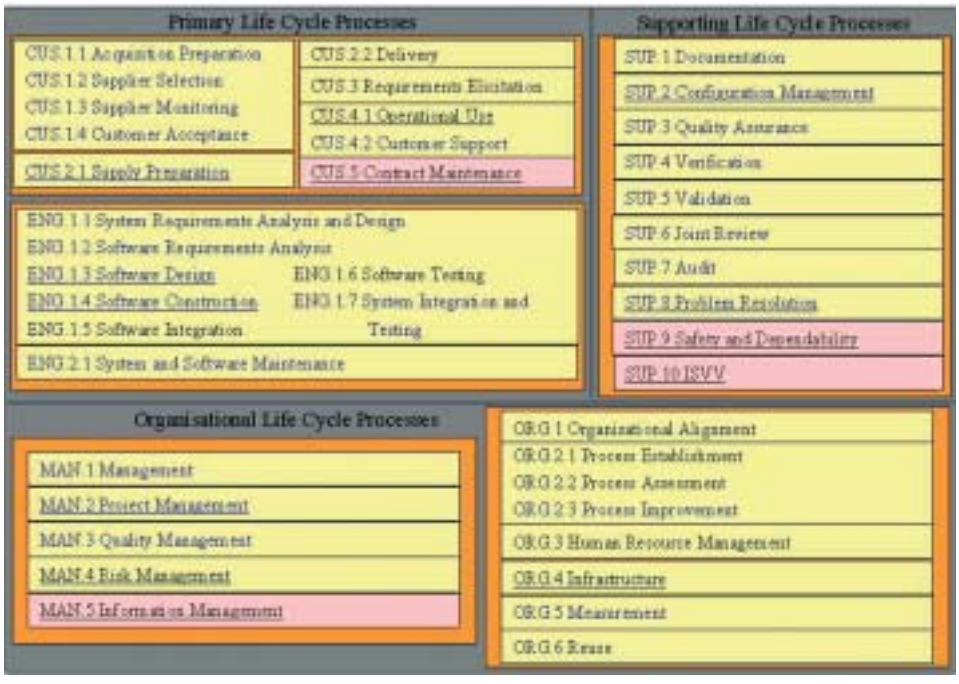


Figure 2. S4S processes and process categories. Processes new to the ISO 15504 exemplary assessment model are shaded in light-grey. Processes with base practices added are represented in bold. Processes with notes added are underlined. Note that CUS.2 from ISO 15504 has been split into two component processes, CUS.2.1 and CUS.2.2

the highly complex and often safety- and mission-critical software produced by the space industry. The new process Independent Software Verification and Validation (ISVV) describes the activities that occur when, for highly critical software, a subset of the standard verification and validation processes is repeated by a third party completely independent from the supplier. The Safety and Dependability Assurance process ensures that the requirements on safety and dependability are defined, that the criticality of each software module is analysed, and that the analyses are updated in accordance with modifications to the software design. Both the ISVV and the Safety and Dependability Assurance processes have been added to the Support category.

Two new processes address general customer and management activities not found in the exemplary model. In the customer category, Contract Maintenance describes the process of maintaining and modifying the contract. Information Management is added to the Management category. This process concerns the installation, maintenance and use of a project information system. Such systems are becoming more common in space projects to facilitate the exchange of project information as teams increase in size and complexity and often work at different locations in different organisations.

Finally, two new component processes stem from splitting the Supply exemplary model process into two processes: Supply Preparation and Delivery. With these two processes, supply activities at the beginning and end of the project life cycle may be assessed separately.

In addition to the new processes, references to and notes explaining the application of ECSS requirements have been added throughout the process model. Inputs and outputs of the S4S processes reflect the ECSS expected outputs. This fusion of ECSS with a comprehensive process framework makes the S4S assessment model a useful guide for companies currently in transition between the PSS-05-0 and ECSS standards.

The assessment process

S4S contains a documented assessment process, which includes a step-by-step breakdown of assessment activities, the definition of key assessment roles, and a description of assessment input and output work products. An S4S assessment is divided into the following seven activities: Initiation, Planning, Briefing, Data Acquisition, Data Validation, Process Rating, and Reporting. In addition to describing the assessment activities, the method offers detailed guidance to assist S4S assessors in each phase of the assessment. For example, experiences from the pilot assessments revealed that during the planning phase, assessors need to clearly understand the customer-supplier contractual relationship and the applicability of standards used in the project to be assessed. Space projects tend to be based on multi-tiered contracts with many levels managed by a prime contractor. Thus, when evaluating space projects, S4S assessors found they had to carefully separate the responsibilities of the project from those of the next-level customer. Expert guidance of this type has been added to the assessment process to incorporate lessons from the space-software perspective into each phase of an S4S assessment.

The S4S method provides three modes of assessment: process improvement, capability determination, and ECSS conformance. The mode selected depends upon the purpose of the assessment. Particular guidance is given for each mode, as the assessment for each is conducted in a different manner. Assessments for the purposes of process improvement focus on identifying areas of improvement or confirming recently implemented improvements in software processes. The results of these assessments are typically for internal use only.

Assessments for the purpose of capability determination may also be motivated by internal initiatives, but are more often the result

of customer requirements. Such assessments provide software customers with assurance of the maturity of software suppliers. Assessment results may be used for the selection of suppliers before a project begins, or for monitoring the performance of an on-going project. With this assessment mode, the S4S method provides a valuable tool for space-software purchasers at all levels of the contractual chain to evaluate and monitor their software suppliers.

In ECSS conformance mode, organisations can use an S4S assessment to determine their compliance with ECSS requirements. In these assessments, the same phases of initiation, planning, briefing, data acquisition, data validation and reporting occur as in assessments for process improvement or capability determination. Identical data may be collected for evaluation. The main difference lies in the interpretation of the data and in the rating scheme.

The tools
To facilitate the efficient performance of S4S assessments, a software assessment tool has been developed, which can be used to view the process model during the assessment, to record process ratings, and to produce the assessment report. This tool has been developed using a commercial SPiCE 1-2-1 assessment-tool engine with a database containing the entire S4S process model. The assessors may view all of the elements that define a given process: purpose, outcomes, base practices and input and output work products. Pop-up windows provide work-product characteristics and process-attribute definitions. A dedicated window allows the user to record the ratings of process attributes. The assessor may also record notes describing the objective evidence found to support his or her judgement. Ratings are displayed in easy-to-read charts. Target profiles may be loaded into the tool and compared with actual results. The S4S data file created by the tool serves as part of the assessment record and can easily be re-examined for future analysis.

Charts, assessor notes, and data recorded in the tool may be exported in standard formats to assist in the production of the assessment report. A standard S4S assessment-report template is provided with macros that automatically import assessment data. Additionally, a set of templates is provided with the method, including Pre-Assessment Questionnaires, Assessment Plans, a Statement of Confidentiality, and Assessor Logs. Sample presentation briefing materials are also provided.

Experiences with pilot and trial assessments
Pilot assessments
To validate the S4S method, four pilot assessments were performed in the last quarter of 1999 at Intecs Sistemi in Pisa and Rome, and at Alcatel Space in Cannes. Their primary purpose was to validate S4S and to provide feedback to further refine the method. A second goal was for the assessors to gain experience in performing assessments in the context of space projects. A third and final goal was to provide potential improvement suggestions to the assessed organisations.

Nine different assessors from ESA, SYNSPACE, and InterSPICE participated in the pilot assessments. The assessment team leaders guided the team in a step-by-step 'walk through' of the method. Feedback was collected from assessors and participants in the form of problem reports. A total of 210 such reports were generated, resulting in a revision of the method to its current version.

Trial assessments
In February 2000, a programme of trial assessments sponsored by ESA to promote the S4S method began. It assessed seven space-software suppliers, in Austria, Belgium, Denmark, Germany, Italy, Sweden and the United Kingdom. A final trial assessment in Belgium is planned for July 2001. The organisations assessed represent space contractors at all levels: prime contractors, equipment/software system suppliers and software companies.

All of these trial assessments were performed with the sole purpose of providing benefits to the host organisations. Indeed, the scope of the assessment, including the choice of processes or projects to assess, was determined by the host. The assessment results, including a measured baseline of process capability and suggested improvement opportunities, remain the property of the host organisations. For their part, the latter agreed to provide feedback concerning their experiences with the S4S assessment, including any suggestions for improvement to the method itself. In addition, they agreed to initiate an improvement programme based on the assessment results and to provide feedback about the efficacy of this programme six to twelve months after the performance of the assessment. Some external support for planning and implementing improvements was also allocated by ESA as part of the trial-assessment programme.

Assessment planning and performance
Initial planning of the S4S assessments began

on average one to two months before the on-site phase. For each trial, two external assessors (from ESA, SYNSPACE or InterSPICE) were provided to plan and conduct the S4S assessment at the host organisation. In several cases, staff from the host organisation also played a role on the Assessment Team, either as assessors or as observers. In general, the assessment teams consisted of two to three people. Whenever possible, assessment planning was expedited through pre-assessment visits by the external assessors, who also provided guidance in selecting the projects and processes to be assessed, with the constraint that the on-site phase should last no longer than one week.

At the beginning of the on-site phase, the assessment team delivered a briefing to the host participants to familiarise them with the S4S model and method. During the rest of the week, the team collected objective evidence of process performance and capability through interviews with project staff and by examining project documents. Evidence was recorded in the assessment record and compiled with the assistance of the S4S software tool. Based on the objective evidence found, the team rated the processes through discussion and consensus. At the end of the on-site phase, the preliminary results were presented to the host organisation to allow for feedback. After the assessment, the team delivered a final report on the results to the host organisation.

Assessment results

Prior to the performance of S4S assessments, confidentiality agreements were made between the assessment teams and the host organisations (hence no company or project names are mentioned and no specific assessment results are presented here). Within the one-week on-site period of an assessment, 10 to 16 processes were assessed for between one and three software projects. On average, approximately 14 process instances were assessed (where one process instance equals one process assessed on one project). In the fourteen projects assessed, on-board and ground-segment projects were equally represented. The projects reflected the five software criticality classes A through E as defined in ECSS–M–00A, with an approximate distribution as follows:

Criticality class	*Percentage of projects assessed*
A	15%
B	15%
C	27.5%
D	27.5%
E	15%

Figure 3 shows the typical capability levels measured for software, on a scale of 0 ('Incomplete') to 5 ('Optimising'). The processes selected for display here are among those most commonly chosen for assessment by the host organisations. For key engineering, support and management processes, typical capability levels of 2 ('Managed') are observed. The Problem Resolution process is often observed at Level-3 ('Established').

Post-assessment improvements

Subsequent to the S4S assessments, improvement efforts based on assessment results have been undertaken at four of the five host organisations. They have already reported initial benefits from the assessment findings, implementing several 'quick fix' improvement suggestions made by assessors with little effort. In several cases, dedicated software process improvement programmes have been initiated; in other cases, improvement actions have been integrated into existing programmes.

For most trial assessments, external support for improvement efforts has also been provided to the host. S4S assessors have supported assessed software suppliers by leading improvement workshops. In these brain-storming sessions, improvement suggestions are discussed, prioritised and grouped. Assessors have also provided support through reviewing improvement plans. Several S4S assessors are currently working with host organisations to determine how to best implement specific improvement suggestions resulting from the S4S assessment.

Feedback from the host organisations about the assessment results has been over-whelmingly positive. Managers found that there

Figure 3. Typical capability levels observed in the S4S trial assessments

was *"significant value"* in having *"shortcomings independently identified and objectively recorded",* and viewed the S4S method as *"a very professional way of performing an assessment and receiving useful results within one week."* In addition to the process capability ratings, some felt that the set of recommendations was the most valuable outcome of the assessment. The cost in terms of workload on the assessed projects was considered 'acceptable' for the benefits gained.

Fulfilling a secondary goal of the programme, the trial assessments have gathered feedback on the S4S method from the host organisations and the assessment teams. These improvement suggestions will be incorporated into future versions of S4S for further refinement of the method.

Owing to the resounding success of the trial programme, a frame contract has been established by ESA to perform more S4S assessments over the next three years. They will focus on the capability-determination assessment mode. The first S4S capability-determination assessment was performed in May 2001 in Spain under this contract. Further assessments are planned, with the next one expected to take place in Portugal.

Process improvement with S4S

As mentioned above, an ESA method of Software Process Improvement (SPI) has been developed for the European space industry. Uniting the continuous improvement cycle of ISO 15504 with SPiCE for SPACE, this approach to SPI provides European software suppliers with the framework necessary for successful process improvement.

The method is based on the eight-step improvement cycle of ISO 15504, Part Seven, with additional guidance incorporated to help space-software suppliers put process improvement into practice. The eight-step model is shown in Figure 4. In the first steps, an SPI programme for the software organisation is established in which target profiles of process capability are defined based on business goals. Periodic software process assessments using the SPiCE for SPACE (S4S) method are performed to provide baselines of the organisation's current process capability. Detailed analysis of the assessment results leads directly to the identification of corrective actions to be performed in the following improvement cycle. These actions are grouped into separate improvement projects, co-ordinated within the overall improvement programme. To confirm that improvements are realised, process metrics are collected throughout the improvement cycle. These steps are described below in more detail.

Examine organisation's needs

In launching a programme of process improvement, a critical first step is the identification of the organisation's needs and business goals. Guided interviews with local management (business, marketing, technical, and quality) may be organised to understand which business drivers (typically quality, cost, schedule or product issues) are of the highest priority. A high correlation has been found between lasting programmes and business-management involvement (and understanding) from the beginning.

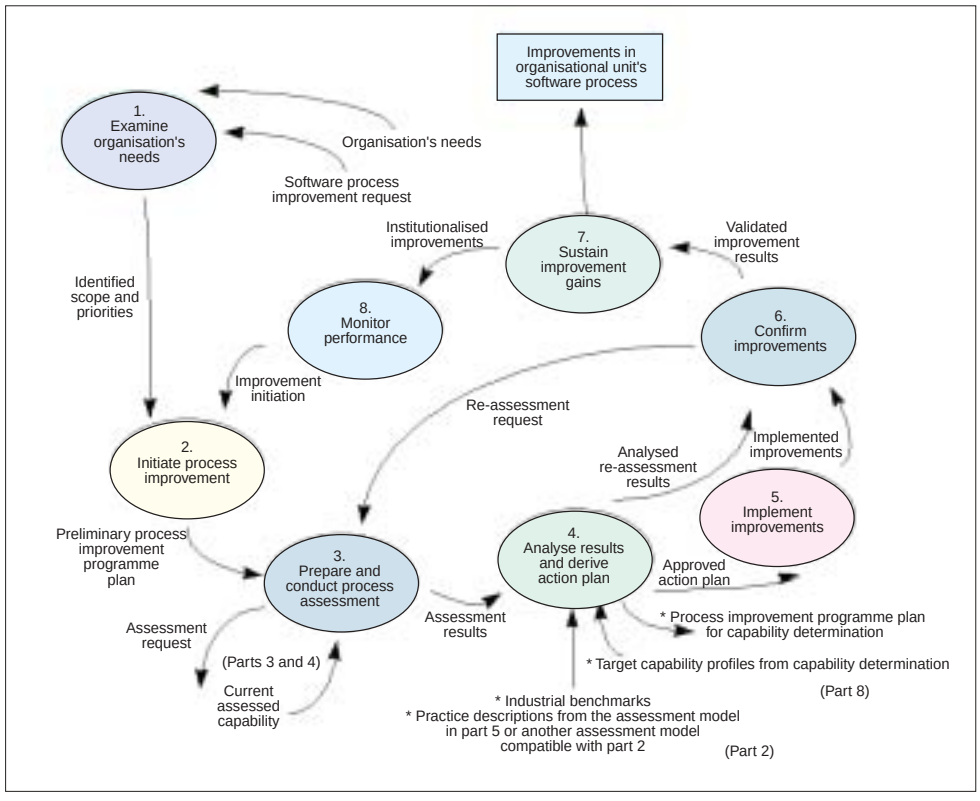
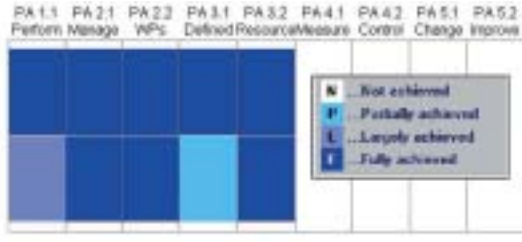


Figure 4. Software process improvement cycle from ISO/IEC TR 15504-7

Based on an analysis of these needs and goals, processes in the SPiCE for SPACE process model are selected for improvement and target capability levels are defined for these key processes. Preliminary target profiles for software criticality classes A to D, following ECSS definitions, are provided in the S4S method and are recommended input. These target profiles will be refined on the basis of benchmarking of the results of assessments performed.

Initiate process improvement
In order to succeed, improvement projects must be managed like any other within the organisation. An overall SPI plan is developed identifying the various phases of the improvement programme and defining goals for each phase. In the subsequent steps, process-improvement projects are initiated based on assessment results and are described in action plans. The overall co-ordination of these individual projects is described in the process-improvement programme plan.



13. ENG. 1.3 Software Design

Figure 5. Example of target (top) and measured (bottom) profiles from a S4S assessment

Typically, the duration of one iteration of the process-improvement cycle is defined by the time between two assessments. Since the delta-assessment should demonstrate a measurable increase in capability levels, this period should not be less than 9 months. At each of the milestone reviews, the results achieved are evaluated against the business goals of the organisation.

Prepare and conduct process assessment
In this step, the S4S method is used to conduct an ISO 15504 conformant assessment for the purpose of process improvement. Outcomes of the S4S assessment include a baseline of the organisation's current process capability. In addition, the Assessment Team compiles a list of general observations, perceived strengths, and potential improvement suggestions for the assessed projects and organisational unit as a whole. The scope of the assessment is chosen so as to cover all processes selected for improvement, and each process is assessed at least up to its desired capability level in the target profile.

In assessments for process improvement (as opposed to those for capability determination or ECSS compliance), the assessment record may be more detailed. As in all assessments, the record contains a justification of the ratings, but here detailed records are included, noting incomplete or unachieved process indicators (base practices, work products or management practices). In particular, anytime the Assessment Team rates a process attribute as less than 'Fully' achieved on any given process, the unachieved process indicators leading to the reduced rating are recorded.

In addition, for unachieved or incomplete indicators, the assessment team records at which level (or levels) in the organisation improvements are needed (e.g. project level, organisational unit, business unit, etc). Certain base practices or management practices in the S4S assessment model are applicable both to specific project environments and to the organisation as a whole.

Figure 5 shows an example, to illustrate the method in practice. It consists of sample assessment results for a project where the process ENG.1.3 Software Design has been assessed up to capability level 3. Five process attributes (indicated on the x-axis) representing capability levels 1 through 3 have been rated for this process. Coloured squares denote ratings for each process attribute (Not, Partially, Largely or Fully achieved). These ratings form a process profile. The top profile represents the target profile (as determined by the organisation before the assessment), and the bottom profile represents the measured profile.

Analyse assessment results and derive action plans
In this step, the results of the S4S assessment are analysed in detail to derive a list of actions for process improvement. This step may be accomplished through workshops held with process performers and other improvement team members post-assessment. After the assessment results are complete, the gap between the target and the measured capability profile is analysed for unachieved or incomplete process indicators. From these unachieved indicators of process performance and capability, a list of corrective actions can be directly derived. This novel step of tracing all corrective actions back to the assessment results keeps the S4S improvement programme on track, ensuring that the knowledge gained in the assessment drives the next round of improvements.

Once the list of corrective actions is complete, an analysis is performed to determine the root cause of the problems identified. In some cases, it may be that the organisational unit was simply not aware that they had to perform certain activities. However, in most cases, an underlying problem prevents the project or organisational unit from fully achieving the indicator(s), although project staff may be aware that this is undesirable. In these cases, it is more important to analyse the assessment data to determine the root cause of the indicators' absence. From this analysis, meaningful corrective actions may be derived. Note that at this stage corrective actions are generic in nature and indicate what should

be done, rather than how it should be accomplished. For each corrective action, there are typically many ways in which it could be implemented. These details are defined in subsequent phases.

Once the corrective actions have been identified, the next step is to group them together based on relationships and inter-dependencies between them. At this point it is essential to gain a more concrete commitment from management concerning the resources that it is willing to consider allocating, and the time frame in which expected improvements are to occur. This knowledge is needed to prioritise the actions and focus the action planning in the following steps. Next, the action groups are validated and prioritised and a strategy is determined for their implementation. For this, the method advises holding work-shops with larger groups of staff within the organisation. Involving process performers at this stage ensures the selection of the most relevant improvements and facilitates their ultimate buy-in within the organisation. Current efforts to incorporate process risk into the S4S assessment method will enable a risk-based prioritisation of corrective actions in a future version of the method (see below). The actions can also be prioritised to reflect the organisation's business goals.

Improvement projects should be classified as short-, medium-, and long-term. Typically, short-term improvements take less than one man-month to implement, medium-term ones take one to three man-months, and long-term ones require more than three man-months. The timeframe for implementing the selected improvement projects can be estimated based on the resources management is willing to allocate for implementation, and dependencies on other initiatives within the organisation.

Confirm improvements, sustain gains, and monitor performance

The method strongly recommends trying out specific improvements with a pilot project, before applying the improvement actions to the organisation as a whole. Process metrics are a key part of the improvement initiative, providing data to confirm gains and monitor performance. A review of process metrication schemes is provided in the method to help software suppliers develop their own customised measurement programmes.

Adding risk analysis to S4S

The S4S method is currently being enhanced by adding process risk as a third dimension to the model. The new version, called SPiCE for SPACE-Risk (S4S-R), will enable software suppliers to target those processes that lead to the highest unacceptable risks, and to make the most effective use of limited improvement resources.

The current S4S assessment method identifies strengths and weaknesses in software organisations and projects. Risks arising from inappropriate process performance or process management are not directly addressed by the method. However, the approach defined in Part Eight of ISO 15504 provides a consistent framework to address such risks. This approach infers process-oriented risks from the existence of process attribute gaps between target capability and assessed capability. The wider the gap, the higher the probability of the related risk. As to the risk's impact, it depends upon the capability level at which the gap occurs.

This approach sets the basis for integrating process-oriented risk analysis into the S4S method where, along with the process and capability dimensions, risk can be considered as a new third dimension. Within the S4S-R framework, a risk analysis is executed post-assessment to help software suppliers select the necessary and minimum improvement actions that meet the organisation's constraints (resources, finance) and goals. As such, the risk analysis provides a powerful tool to help define a programme of software process improvement.

The S4S-R tool is expected to provide a new view on process-assessment results, which will:

– highlight the most significant software process risks, and
– focus process-improvement activities on the key problems of the organisation.

The extended tool may also be used to generate effective process improvement actions that reduce the magnitude of the most significant risks.

Conclusion

Founded on international and European standards and supported within a framework of process improvement and process risk analysis, the S4S assessment method is the cornerstone of an emerging initiative of process improvement across the European space industry.

The work reported has been conducted under an ESA/ESTEC Contract.