Concurrent System Engineering in Air Traffic Management: Steering the SESAR Program

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Abstract As a “System of Systems” (SoS), Air Traffic Management (ATM) in Europe will be improved by simultaneous and coordinated evolutions of its constituting systems. The SESAR Program aims at reaching an ambitious performance target (for 2020) by developing a large collection of “Operational Improvement Steps” (OIs). This development is achieved by more than 300 projects, themselves involving a number of partners working at their own site throughout Europe.

To face this challenge, the SJU supported by EADS through an “industrial support” contract, has organized the management of the contributing projects on some basic principles:

- The SESAR Program is **Performance-driven**: this principle gives priority to developments that demonstrate significant performance gains within Key Performance Areas (KPA)[1].
- The programs **monitors the maturity** progress of the constituting OIs on a maturity scale (V1, V2, V3 maturity levels introduced by the European Operational Concept Validation Methodology) and revisits their priority in accordance with their maturity status.
- The achievement of each maturity level corresponds to a phase, and the transition from a maturity level to the next is assessed on the basis **of maturity criteria**.
- Each maturity criterion shall be demonstrated though evidences**, relying on validation results**.
- Maturity criteria reflect the confidence that the Requirements attached to OIs will be met. In particular, the confidence in meeting the performance

[1] The Key Performance Areas are: Safety ; Security ; Capacity ; Cost effectiveness; Efficiency ; Environmental sustainability ; Flexibility ; Interoperability ; Participation ; Predictability; Access and Equity.

targets (considered as a particular category of requirements) is a key maturity criterion: therefore, the accuracy of the performance results (based on platform measurements) supports the estimation of the confidence that the performance target will be met. So, the **maturity progress** includes **de-risking the level of performance**.

- For each OIs, a **validation strategy** is defined to ensure that the proper validation activities are planned by the relevant projects and aligned with programme priorities.

The SESAR Research and Development methodology therefore implements a progressive de-risking / Validation approach, considering the performance gains and confidence to support the maturity assessment. This approach permits to efficiently drive the program on Performance, by re-allocating, when necessary, the resources to the most significantly promising performance gains.

To give an example, let us consider two key performance areas: safety (characterized by a number of near-collisions or runway incursions) and capacity (characterized for example by a number of flights in airspace volume or runway movements per hour). Some performance figures, exploring several operational scenarios can be early obtained by fast time simulations and Monte-Carlo analysis. Initial performance results may be sufficient to support trade-offs between performance features, and to feed cost-benefit analysis supporting a decision to proceed or not (or rather to increase/ decrease the priority). Conversely, real flights with representative equipment in all the systems that contribute to the considered OIs may be costly and not suited to explore the solution performance in all relevant scenarios (e.g. nominal and off-nominal situations). So, exercises with real flights in representative operational environment will be mostly suited to assess maturity areas remaining to be validated (such as human factors).

2 Introduction: the SESAR Program

The SESAR program is the technological part of the Single European Sky initiative. The current phase addresses the Research and Development (R&D) activities to define the Operational concept and technical solutions to meet the challenging performance targets for 2020:

- 27% increase in Europe's airspace capacity,
- 40% reduction in accident risk per flight hour despite an increase in air traffic,
- 2.8% reduction per flight in environmental impact (e.g. C02 emission),
- 6% reduction in cost per flight.

The SESAR program deals with a collection of pre-identified Operational Improvement steps (OIs) and corresponding Enablers (ENs) that need to be matured in two ways:

- refinement of their definition,
- verification and validation (V&V) aiming at increasing the confidence in their feasibility and ability to achieve the requirements, including allocated performance requirements.

The R&D activities are achieved by a high number of entities (Air National or International Service Providers and Industrials) that have their own methods, interests, and program of work but share the common goal to integrate the validated improvements in their operational environment and products.

SESAR Features:

- more than 300 projects working in parallel on around 40 Operation Focus Areas
- 3 steps (2013 – 2015- 2017) planned,
- 200 Operational Improvement steps (OIs) already identified

3 Methodological considerations for a R&D program

The classical V-cycle (waterfall) is a valid reference to conduct the proper development and validation of the concepts and solutions. The V-cycle is used as a reference to harmonize (or internally standardize) the development and validation activities and documentation.

Two methodological considerations, meaningful in any System of Systems R&D programme, are discussed hereafter:

- Top-down versus bottom-up design approach,
- "incremental" and "spiral" development methods.

3.1 Top-down versus bottom-up in a R&D program

In the commonly accepted meaning, top-down development refers to the derivation of high-level (user) requirements down to lower level (system / component levels). In the SESAR case, top-down here means that the driver is the performance target.

Bottom-up here reflects the fact that some Operational concepts or Operational Improvement steps and Technological evolutions (of Technical Enablers) are defined and developed by the experts as a result of local needs rather than by a direct derivation of higher level requirements.

In a R&D program, the solutions are often proposed spontaneously by the experts and even their refinement results from the deepening of emerging ideas rather than from a mere problem-solution development.

So this apparent contradiction can be resolved by applying a "selection" process, based on the joint assessment of maturity and performance. If a solution, based on the validation results, is not promising enough in terms of contribution to the global performance targets it could be rejected in favour of a more promising improvement.

3.2 Incremental versus spiral development

In a classical development, resource and risk management lead to develop successive increments. In a R&D program, it is preferable to take into account the results of a validation stage before deciding investment to further develop / mature the considered operational improvement.

The two approaches: incremental and evolutionary or spiral are briefly compared hereafter (reference [1][2] can be considered for the definition of these terms).

3.2.1 Incremental development

The incremental build model is a method of development where the solution is designed, implemented and tested incrementally. The product is defined as finished when it satisfies all of its requirements. This allows partial utilization of product and avoids a long development time. This incremental implementation support stakeholders confidence, as incremental improvements progressively introduce partial capabilities.

In the SESAR program, 3 steps have been predefined with corresponding sets of OIs . Their development and validation are planned over several years in high-level roadmaps (release strategy and Validation roadmaps). In a sense, the SESAR program is basically incremental, where "block builds" correspond to the pre-planned content of the 3 steps.

3.2.2 Spiral development

The spiral development model process combines advantages of both top-down and bottom-up approaches. It combines the features of the prototyping and the waterfall model. The spiral model is suited to large, expensive and complicated systems.

In practice, in the SESAR program, the full set of OIs and Enablers was not fully and precisely defined at the beginning. Due to the R&D nature of the Programme, most of them need to be refined or modified according to the results of the ongoing experiments and development activities, supported by prototyping.

[2] Reference [1] defines Evolutionary in the following way: "Plan, specify, and implement an initial system capability. Gain experience with the initial system and define the next iteration to fix problems and extend capabilities. Refine the Concept of Operations, add and change system requirements, and revise the design as necessary. Continue with successive iterative refinements until the system is complete. This strategy can be shown as a series of "Vs" that are placed end to end since system operation on the right side of the "V" influences the next iteration. …For particularly complex projects, a *spiral model* may be used, which is an evolutionary approach that is driven by risk management and extensive planning in each iteration. In the spiral model, the initial iterations include prototyping, analyses, and studies that are intended to reduce risk prior to implementation of an operational capability. The products in each iteration are defined to reduce risk as the system's degree of definition and implementation is increased incrementally."

4 Key SESAR System Engineering Management features

4.1 Discrete Operational Improvements steps

The Operational Improvement Steps are the smallest elements of the Operational concept. They have initially been defined during the Definition phase of SESAR and are permanently refined during campaigns. Their implementation into the real ATM system has been planned with Initial Operational Capability (IOC) dates set assuming an initial maturity.

These Operational improvements rely on several Enablers (ENs), including in particular the System Enablers based on technological development.

OIs having strong dependencies and contributing to the solution of the same problem may be grouped into a “SESAR Solution” to be jointly validated. For the sake of simplicity we consider in the sequel that SESAR solutions are OIs.

At the end of the operational concept development activity, all Operational Improvement steps are characterized by operational and performance requirements and all related System Enablers are characterized by technical requirements. In most cases, the performance requirements are initially set in a qualitative way and are more precisely defined during the maturation process.

4.2 Development and validation stages in SESAR

With reference to the classical V-cycle, the development and validation activities of OI steps follow the generic stream:

- Concept definition, Definition of Operational Requirements, along with their Safety and Performance Requirements, Operational Concept development and, simultaneously, Validation plan production,
- Development of System Requirements meeting the Operational Requirements (for all Systems contributing to the corresponding Operational Improvement) , and simultaneously production of the Verification plan,
- System solution development with prototypes and platform integration,
- Verification that each System satisfies its requirements,
- Validation of the operational concept and related performance.

Standard SESAR documentation has been defined to ensure the consistent development of requirements and validation objectives.

4.3 The SESAR performance target

The performance target addresses Key Performance Areas (KPAs), with corresponding Key Performance Indicators (KPIs) for the overarching ATM system of systems.

The political targets are split over each of the 3 program steps.

The KPIs are broken down in a number of Performance Indicators (PIs) with associated metrics. PIs are related to KPIs via modelling techniques called Benefit Mechanisms. PIs are measured during validation Exercises.

Managing the performance targets on PIs as requirements, allow linking the political target and project activity.

So the validation activities allow risk-reduction as regards performance. Indeed, the performance uncertainty decreases and confidence that the performance target will be met increases (as notionally represented in the figure below).

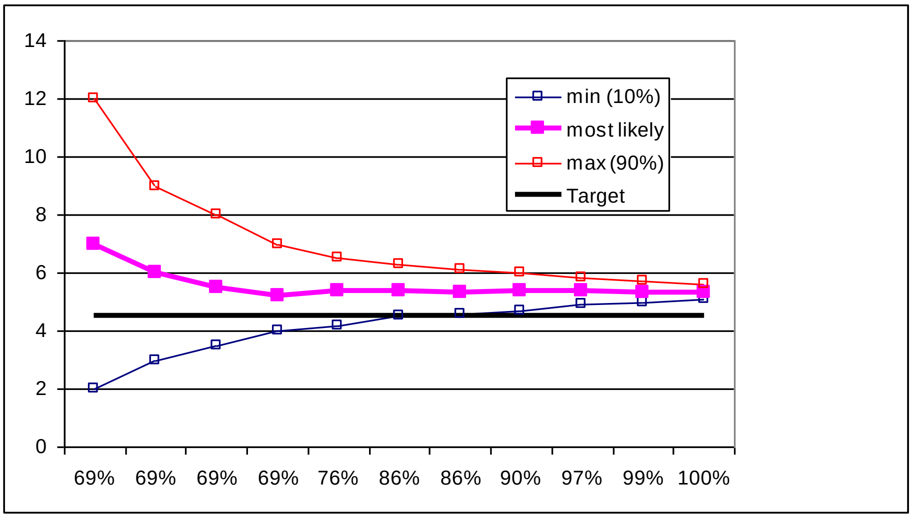

Figure 1: notional representation of performance uncertainty reduction along with validation activities

(In this case, the probability that target is met increases with time)

4.4 Maturation and program steering

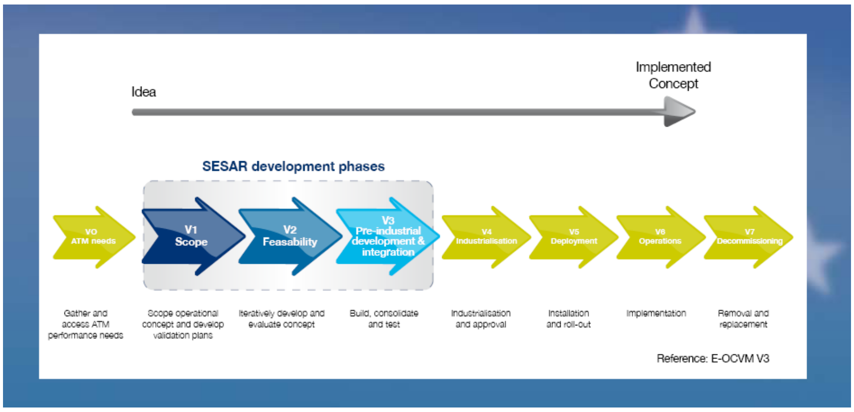

Figure 2: SESAR within the E-OCVM lifecycle

SESAR covers three phases of the E-OCVM lifecycle: V1, V2 and V3. These three phases correspond to 3 development iterations of the development process, ending to increasing level of maturity. The SJU has developed a set of criteria to address the 3 transitions: V1 to V2, V2 to V3, V3 to V4.

For each OIs, a validation strategy is defined to plan sequence of activities that end to a completely V3-mature delivery at a date compatible with the planned IOC date (generally, V3 should be completed at least 2 years before the IOC to let sufficient time for eventual V4 industrialization and certification activities). A "top-down Verification and Validation Roadmap" is regularly updated to refine the planning of validation activities in accordance with the validation strategy.

Every year, the V3 activities for the coming year are planned with a high level of detail to ensure the concepts will be fully V3-validated at the end of the next year: this "Release" approach intends to deliver each year a set of V3-validated OIs.

The management of a Release lays on 3 System Engineering reviews. At the last one, the actual maturity is assessed based on the provided evidence, including Validation-Exercise-Reports. If most V3-to-V4 criteria are satisfied, the corresponding OIs are "released" by the SESAR program.

Monitoring the maturity supports the decision to proceed to the next phase and to continue investing into solutions. This monitoring process takes place from initial V1 to V3 maturity level, with increased attention at the latest stages (especially in Release monitoring). Such a continuous monitoring supports decision to stop, redirect or reallocate resources towards the most beneficial OIs, with consideration of their time-horizon.

5 Conclusion: the SoS concurrent design challenge

The SESAR program addresses concurrent engineering of a large System of Systems. As such, the various developments of all its constituting elements need to be coordinated, taking benefit from both top-down approach and from the use of successive development and validation activities to improve the definition of the Operational concept elements.

Strict monitoring of maturity and steering the program based on the expected performance benefits ensure that the parallel developments and validation activities, achieved by 300 projects working in parallel, are properly synchronized and steered.

This has been permitted, within SESAR, by defining standard levels and standard maturity criteria and by imposing a pace with annual releases and synchronization points. Such an approach demonstrated its efficiency, since 2013 will see the 3rd Release of V3-validated sets of OIs, grouped into SESAR Solutions.

However, consolidating results and feeding back, to properly drive the program from the performance view, has demonstrated to be uneasy, and remains a challenge.

References

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For more information on SESAR, visit www.sesarju.eu or contact communications@sesarju.eu .