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NEW KEY SUCCESS FACTORS FOR ENGINEERING TECHNOLOGY TRANSFER BETWEEN RESEARCH AND DEVELOPMENT: TECHNOLOGY MATURITY AND PROOF OF USAGE

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ABSTRACT

Investment on Research and Technology (R&T) projects is a competitiveness key and contributes to study and develop innovative technologies. However, the success of the technology transfer between research and development projects is essential. In Eurocopter context, R&T projects are monitored thanks to the Technology Readiness Level (TRL) methodology. Developed by the NASA, it assesses the maturity of aircraft technology products in terms of efficiency, engineering, manufacturing and support means. The aim of this article is to enhance the technology transfer between research and development projects in the case of engineering technology product. Once developed, engineering products (DMU, PLM) are used by engineers during aircraft development programs. But how can teams manage with success the technology transfer of engineering products? In this paper, enrichments of current TRL methodology are proposed with a new key success factor: the proof of usage. The idea is to anticipate during R&T projects future usage of engineering technology products thanks to scenarios modeling. In this frame, a new approach is proposed and validated based on a Eurocopter case study.

Keywords: technology transfer, engineering technology product, maturity, proof of usage, scenario

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1 INTRODUCTION

Research and Technology (R&T) projects are critical to maintain industrial competitiveness. They initiate innovation processes by producing technology products, which could be then developed and deployed in product development programs depending on their added value. In the Eurocopter context, aircraft technology products are for example new blade materials or new main gear box. R&T projects are good opportunities to study and ensure that new technology products are enough mature and that their future integration into aircraft development program presents a minimum of risks and uncertainties. Technology product maturity, and so level of risks and uncertainties, is assessed all along R&T project advancement thanks to the technology readiness level (TRL) methodology (see Section 1). To be integrated inside an aircraft development program, as illustrated on Figure 1, aircraft technology products have to reach a TRL 6 (see § 1.1 for more information). Technology readiness levels could be understood as Go/No-Go gates.

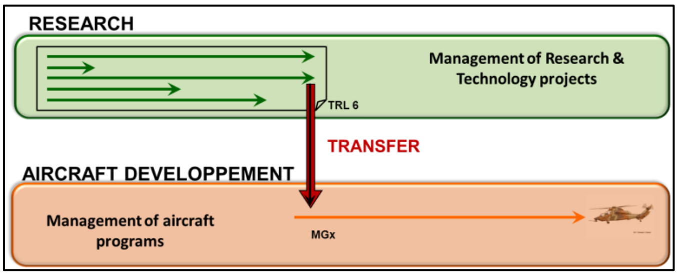

Figure 1.Technology transfer between R&T projects and aircraft program development

In Eurocopter context of study, R&T projects produce not only aircraft definitions but also engineering technology products, as illustrated on Figure 2. Engineering technology products are tools and methods used by designers during aircraft development, as for example the digital mock up or the different simulation data management tools. Engineering technology products aim so at improving the designers' ways of working during aircraft development program.

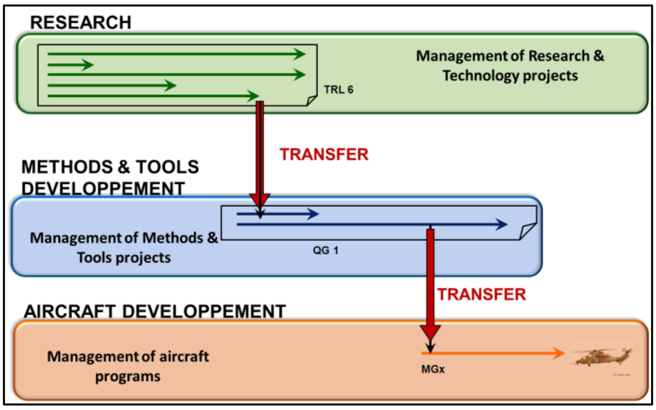

Figure 2. Technology transfer between R&T and M&T development projects

Engineering technology products are then studied during R&T projects and integrated into Methods & Tools (M&T) development projects. M&T development projects have the objective to provide new technologies which will be used without risks in the aircraft program.

Two technology transfers are identified: transfer between R&T and M&T projects and then between M&T and Aircraft development projects. The success of the second transfer depends on the first one. **But what are the key success factors of the technology transfer between Research and M&T development? Is the TRL methodology sufficient for supporting such a technology transfer?** Furthermore M&T projects could integrate several technology products studied during R&T projects. **How to be sure that technology products developed independently during different R&T projects would be able to be integrated then into M&T development project? How to anticipate integration issues during R&T projects?**

Engineering technology products have not only to be of high efficiency from a scientific and technical point of view, but they also have to be accepted by their future users. In other words, the proof of usage of engineering technology products have to be verified and validated as soon as possible during R&T projects.

New resources must be proposed in order to support the technology transfer between R&T and M&T projects. The TRL methodology is a basis. **Which resources could be associated to the TRL methodology? How to better anticipate the proof of usage of engineering technology products? How to qualify those resources?**

The study was realized in Eurocopter, a helicopter manufacturer belonging to the EADS worldwide group. An action research methodology was applied in order to propose answers to our research questions. As an actor of R&T but also of industrial projects, the researcher analyzed the AS-IS situation of the technology transfer. The analysis pointed ways of improvement, solved by the integration of new resources inside the TRL methodology: usage scenario and proof of usage. A usage scenario methodology was developed, based on the analysis of a case study.

The first Section of the article explains the major concepts used as the TRL methodology, the proof of usage and the usage scenario. Then the second Section focuses on a Eurocopter case study. Finally the proposed methodology is discussed and perspectives of the work are identified.

2 DEFINITION AND CONCEPTS

2.1 Maturity of technology product

Research and Technology projects aim, in one hand, at creating new technology products and, on the other hand, at anticipating the integration of results into development projects. In Eurocopter, aircraft technology products are evaluated through their maturity. The maturity assessment is performed thanks to the technology readiness level (TRL) methodology, developed by the NASA (Department of Defense 2011). A TRL is a key milestone where the transition from each TRL requires a review to ensure that specific criteria have been completed and validated. The methodology is built around nine levels of readiness (Mankins 1995).

The maturity assessment of each TRL is based on four maturity topics:

- the technology product efficiency,
- the engineering means necessary for future development,
- the manufacturing means necessary for future deployment
- the support means necessary for the technology lifecycle

Associated to each of the four topics, criteria are defined. For each TRL, during an assessment review, evidences are proposed in order to assess each criterion. The higher is the TRL, the more detailed the criteria and evidences have to be.

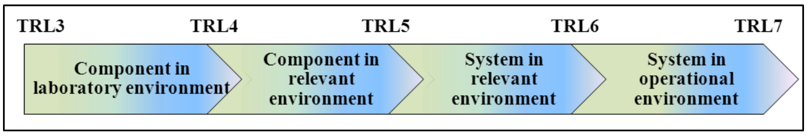

Figure 3. TRL scale

The TRL 6 is a critical level. Indeed, as described in Figure 3, it characterizes the transition between a relevant and operational environment. Relevant environment simulates characteristics of operational environment but in R&T context. The TRL 6 represents an input for the first level of applied research. A technology product could pretend to a development only when its maturity reached a TRL of 6.

To sum up, the TRL methodology aims to anticipate and solve risk and uncertainties related to the **integration of a technology product from research to development context.**

The TRL methodology developed by the NASA and used in Eurocopter only concerns aircraft technology products. However our study focuses on engineering technology products (dedicated to designers). **Is the NASA TRL methodology adaptable to this type of technology products? Are the four maturity topics proposed in the NASA methodology (efficiency, engineering, manufacturing and support means) adaptable and adequate for the maturity assessment of engineering technology product in R&T context?**

2.2 The proof of usage

The TRL methodology contributes to anticipate during R&T projects risks and uncertainties of the technology product future development. Today, the methodology highlights the proof of concept of aircraft technology product. The proof of concept brings evidence that the technology product “works or it is likely to work in situations it is expected to be delivered” (Yannou 2012).

However, engineering technology product could be efficient from a technical point of view but could be, at the same time, unadoptable by future users. Engineering technology products have to take into account user’s requirements. It is therefore important to anticipate and identify, during R&T projects, future usage of engineering technology products. In other words, in R&T project, engineering technology products have to be studied with a user-centered and more precisely a usage-centered approach. A new resource, the proof of usage, is so defined in order to anticipate future usage linked to the development context.

Engineering technology products answer business and technical issues (while aircraft technology products only answer technical issues). They improve a current situation, the AS-IS situation, and are used in a new way of working: the TO-BE situation (Cornu 2012). The AS-IS situation contributes to formalize ways of improvements and so user’s requirements, which have to be integrated into TO-BE situations.

AS-IS and TO-BE situations could be modeled in order to describe involved actors, theirs activities and relationships, data exchanges, tools, interfaces and policies.

TO-BE situations illustrate future usage of technology products. Finally, the modeling and analysis of AS-IS and TO-BE situations validate the proof of usage of engineering technology products, as illustrated on Figure 4.

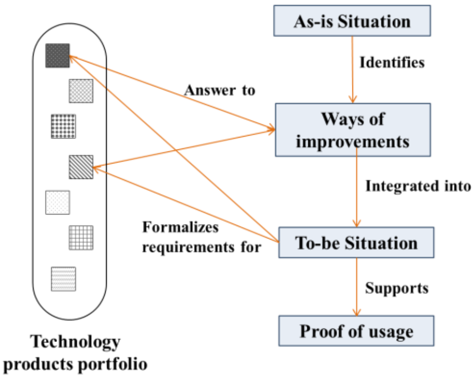

Figure 4. Relationships between Technology Products, AS-IS/TO-BE situations and Proof of usage

The proof of usage is based on system engineering principles (Haskins 2010), (Department of Defense 2001). Indeed, it aims at developing complex systems (Faulconbridge & Ryan 2003), technology products, which requirements have to answer AS-IS situation improvement.

By creating a TO-BE situation, users formalize and illustrate engineering technology product requirements and propose a context of usage and of validation (Hallam 2001). Therefore the execution of the TO-BE situation contributes to monitor the study of technology products in R&T context: do technology products characteristics allow executing with success the TO-BE situation?

Including the proof of usage in the TRL methodology contributes to improve the maturity assessment by adding a usage view. But **who build and how are built AS-IS and TO-BE situations?**

2.3 Scenarios

Scenarios are used with different goals in various domain as human-computer interface (Carroll & Rosson 2002), software and system engineering (Jarke & Carroll 1999), (Sutcliffe 2003) or strategic management (Schoemaker 1995). Definition of scenario depends on the scientific community but some characteristics are common and shared.

A scenario is a tool that obliges to forecast future. It relates interactions between various elements under certain conditions (Schoemaker 1995) and therefore, challenge mind-set and open-minding. (Carroll 1995) shares this point of view and precises that scenario describes particular instances of use, and on a user‘s view of what happens, how it happens and why. Scenario are close to behavior, usage and more precisely to usability and utility (Pascal & Rouby 2006).

Several futures of a current real world experience are conceivable. Thus several scenarios are also possible.

Models (narrative text, use case diagram) are used for formalizing scenarios in order to share a common understanding between various stakeholders. For (Julien et al. 1975), scenario is a paradigm: a research and analysis tool halfway between image and model. Scenario is less complex than a model but more pertinent than an image.

Furthermore scenarios support decision making by illustrating constraints, requirements and impacts of possible futures.

However two major inconvenient have to be mention: scenarios are context dependent and imply biases in their construction. It is therefore important to use scenario in order to identify patterns and so to generalize some elements of behavior or functionalities of a system for example.

R&T projects investments allow studying new technology products. However it is important to monitor investment and so R&T projects advancement. Return on investment will be realized if studied technology products would be then developed in Methods & Tools projects and then used during aircraft development.

Scenario during R&T projects is a resource for supporting the study of future usage and impacts of technology products. Scenario supports the proof of usage assessment. Indeed AS-IS situation could be assimilated to the description of the current usage scenario. By analyzing the AS-IS scenario, TO-BE proposals could be formalized. TO-BE usage scenarios illustrate the use but also interactions of technology products inside a process.

3 COUPLING THE PROOF OF USAGE CONCEPT WITH THE TRL METHODOLOGY: A NEW APPROACH

The NASA TRL methodology proves the concept of aircraft technology products. We highlight that new resources have to be proposed in order to evaluate risks and uncertainties of engineering technology products in an R&T context. A proof of usage, associated to usage scenarios, is defined. It aims at anticipating and including the notion of use and of user’s adoption.

We then proposed to integrate these new resources inside current TRL methodology in order to enrich it.

The new methodology is applied from TRL 3 to TRL 6 during R&T projects. Three phases are defined and applied for each TRL.

- ➢ PHASE 1: Analysis of usage scenarios
    - First Step: Description and analysis of the AS-IS usage scenario: it is a diagnostic step which describes how stakeholders work and collaborate in order to answer technical and business issues. The description of the AS-IS scenario contributes to point ways of improvement.
    - Second Step: Description of the TO-BE scenario: it is a picture of an improved AS-IS scenario which implies the use of new engineering technology products. It is important to model the TO-BE scenario in order to understand all the activities, actors and data exchanged but also the interfaces between technology products.

For each scenario description, following items have to be identified:

- Actors and their roles
- Activities and tasks with their inputs and outputs
- Relationships between activities
- Resources
- Information and their flux

Those items are collected thanks to individual and collective interviews with stakeholders. The work is iterative and based on a business modeling under BPMN. Different views could be modeled:

- functional view which describes the process of use
- informational view which describes objects, information and their relationships
- organizational view which describes actors and responsibilities
- resources view

- ➢ PHASE 2: Study of engineering technology product prototypes
  - First Step: Formalization of requirements: the implementation of a TO-BE scenario has to be prepared and all impacts anticipated. The first step is to identify all the requirements related to the architecture of the technology products but more largely to the process, tools and methods of the TO-BE scenario. All the requirements are gathered in a deliverable named ‘Requirements Dossier’.
  - Second Step: Development of all necessary technology products: most of the time technology products are already developed thanks to research project but they have to be adapted to the previous identified requirements.

- ➢ PHASE 3: Prototypes validation and TRL assessment
  - First Step: Execution of the TO-BE scenario in the TRL associated environment:
    - o At TRL4, critical components are developed and tested with simplified data in a laboratory environment
    - o At TRL5, the whole system is developed and tested with simplified data
    - o At TRL6, the whole system is tested with real data

Associated to the proof of usage, a work has been done on the TRL survey in order to adapt maturity criteria to engineering products. For confidentiality reasons, the survey and proposed criteria could not be shared.

  - Second step: Validation of the adequacy and coherency between the TO-BE scenario developed and the initial requirements. The maturity is assessed thanks to the TRL survey, based on evidence provided by the TO-BE scenario.

In practical, usage scenarios are integrated as a cycle process into the linear TRL process, as described on Figure 5. The AS-IS scenario is defined when TRL 3 is assessed and it is not modified all along the process.

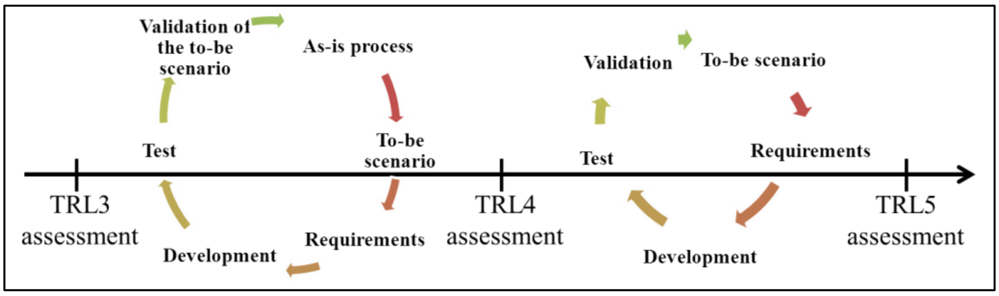

Figure 5. Description of the two interlocked processes between TRL 3 and TRL 5: TRL linear process and cycle usage scenario process

4 VERIFICATION AND VALIDATION OF THE APPROACH ON A CASE STUDY

The new methodology was developed thanks to a verification and validation on a Eurocopter case study. The case study deals with the improvement of thermal analysis processes of the aircraft engine’s integration in a collaborative way. Indeed, the issue of engine integration implies a lot of expertise (manufacturers, equipment suppliers, suppliers, software vendors) but also numerous models, tools and data format.

4.1 Phase 1-Step 1: description of the AS-IS usage scenario

The AS-IS usage scenario deals with two issues:

- A technical issue consisting in the thermal integration of helicopter engine into its compartment. The compartment, closed by the hood of the helicopter, contains a structure (engine and equipment) and must allow the circulation of a cooling fluid (air flow). Ventilations have to be designed on the compartment in order to ensure the cooling.

  The issue implies an engine manufacturer and three engineers: a CAD designer, a thermal and an aerodynamic engineer.

- A business issue consisting in ensuring a collaborative work between actors. Currently, actors work with different tools in different firms. They deal with data exchange troubles because of different data formats but also because of non-interoperable tools and confidentiality issues.

The case was studied in the frame of a European research project named CRESCENDO (CRESCENDO n.d.). The AS-IS scenario describes all activities currently implemented for answering the technical and business issues. It was described in narrative text but also modeled with business process notation (BPMN). The model was built by one of the actors, progressively thanks to interviews and reviews with others actors. Because of confidentiality restriction, the business process model could not be shared. A high-level process, represented in Figure 6, is rather proposed.

Four actors are represented: the engine manufacturer, the CAD designer of the design office, the aerodynamic engineer and the thermal engineer. The AS-IS process model is mostly sequential. Ten main information flows leaning on activities, each of them modeled by an arrow, are identified:

1- The engine manufacturer sends the engine CAD representation (a skin model) to the designer who integrates it into the global helicopter digital mock-up (DMU)
2- The designer simplifies the DMU thanks to advice of the thermal and aerodynamic engineers. The simplification would facilitate the modeling and calculation.
3- The idealized CAD representation is sent to the aerodynamic engineer who starts the meshing.
4- The aerodynamic meshing is sent to the thermal engineer.
5- And 6- In parallel, the thermal engineer exchanges with the engine manufacturer in order to obtain engine thermal behaviors for different helicopter flight points.
8- The thermal engineer sends to the aerodynamic engineer the thermal characteristics of the engine, obtained by extrapolation of engine manufacturer abacus.
7- The aerodynamic engineer simulates the velocity fields around and inside the engine compartment.
9- Velocity fields are sent to the thermal engineer.
10-Thermal fields inside the engine compartment are modeled and the ventilation design is verified

The flows 3 to 10 are run for each ventilation design; and for one ventilation design, flows 7 to 10 and activities associated are run iteratively until the convergence of thermal fields.

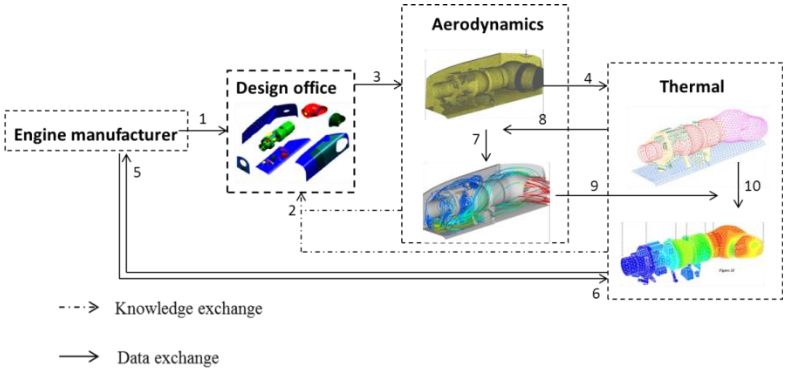

Figure 6. Model of the AS-IS usage scenario

The model of AS-IS scenario is the common resource shared by actors. Thanks to this view, ways of improvement are identified:

- new tools for tracing and storing all data and knowledge exchanged
- new working method in order to facilitate meshing step but also in order to reduce the number of model data set up and calculation
- new modeling and simulation workflow.

4.2 Phase 1- Step 2: description of the TO-BE usage scenario

Based on the analysis of AS-IS scenario and also on identified ways of improvement, actors of technical and business issues proposed a TO-BE scenario. As for AS-IS scenario, a TO-BE model was realized and a simplified view is described in Figure 7.

Four improvements mainly appear in the TO-BE process. Firstly, the modification of the simulation workflow is the most important change. An iterative cycle of distributed simulations is developed in order to refine results. It is why the design office sends (arrow 3) to both thermal and aerodynamic engineers the idealized DMU who work separately on their meshing.

The aerodynamic engineer starts the iterative cycle by calculating velocity fields of the helicopter (arrow 4). Exchanged conditions at the interface fluid/airframe are sent to the thermal engineer (arrow 7). Thanks to those parameters and coupled to the thermal engine characteristics, the thermal engineer simulates the thermal and velocity fields in the engine compartment (arrow 8). Those outputs are then sent to the aerodynamic engineer (arrow 9) who uses them for simulating the fluids velocity. His calculation refines the convective limitations on the compartment and refines the thermal simulation (after arrow 10). All along the calculation workflow, the thermal and aerodynamic engineers control the convergence of their modeling parameters. The calculation workflow is an engineering technology product that improves the AS-IS scenario.

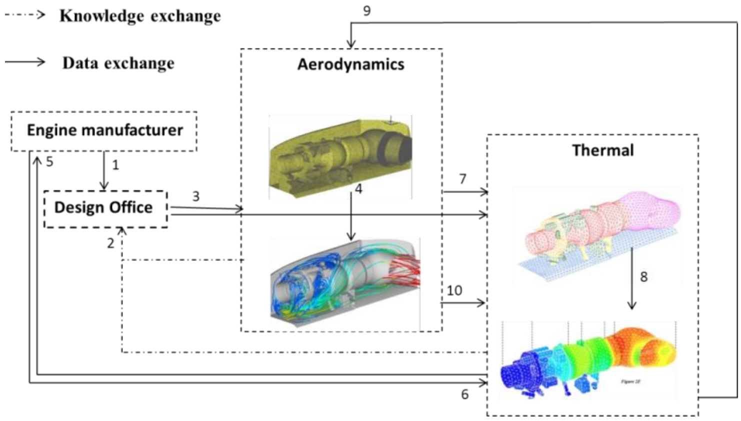

Figure 7. Model of the TO-BE scenario

Associated to this workflow, a second engineering technology product has to be developed: new tools for model set-up and calculation more interoperable between thermal and aerodynamic domains.

Changes have also to be realized about the parameters exchanged between the engine manufacturer and thermal engineer (arrows 5 and 6). The thermal engineer needs to understand the thermal engine behavior for different flight points of the helicopter. In the AS-IS scenario, the engine manufacturer sends abacus and, thanks to an extrapolation, the thermal engineer was able to obtain the desired parameters. However, results are not precise. In order to solve and improve those exchanges, a third technology product has to be developed: a surrogate model of the thermal engine behavior.

Finally, a data management is identified as a way of improvement in order to answer technical and business issue of the usage scenario. The aim is to trace all exchanges of parameters and data.

4.3 Phase 2- The engineering technology products

The TO-BE scenario illustrated the use of four new technology products, summarize in Table 1.

Table 1. Technology products to develop in the TO-BE process of the usage scenario

TP	Technology product	Action solved
TP1	Collaborative calculation workflow	Iterative automate calculation workflow in order to reduce the calculation time, to simplify the thermal filed simulation. Imply that thermal and aerodynamic tools are interoperable
TP2	New tools and methods for model set-up and calculation	A benchmark is realized in order to find the best tool for each thermal and aerodynamic discipline with the best interoperability
TP3	Surrogate model of the engine	Improvement and better precision of the engine behavior at different flight points of the helicopter
TP4	Data management	Data management in order to trace and store all knowledge, parameters and data exchange all along the TO-BE process. It allows to reduce rework and the lifecycle time of the product

The TO-BE scenario also illustrates all the interactions between the technology products themselves and with the firm ecosystem (others tools, application, policy, methods proper to Eurocopter).

Thanks to the TO-BE scenario view, actors are able to formalize technology product requirements and to study and develop related prototypes. The development of prototypes is linked to the level of readiness (TRL) studied:

- at TRL3, technology products are concept
- at TRL4, only critical functionalities of technology product are developed and tested separately with simplified data
- at TRL5, the four technology products are integrated into the TO-BE situation and the whole process is tested with simplified data
- at TRL6, the TO-BE scenario is tested (and so technology products) with real data → the TO-BE scenario represents the future way of working, which means the development and deployment environment.

4.4 Prototypes validation and TRL assessment

The AS-IS and TO-BE models, associated to the study of the gap between the two usage scenarios, contribute to the formalization and development of four technology products. The final aim is to industrialize technology products developed in TO-BE scenario. Therefore the TRL assessment and the proof of usage have to be validated.

The TRL assessment is linear and gradual. In the context of the case study during CRESCENDO research project, the targeted level is TRL4.

The proof of usage of the four identified technology products rests on the execution of the TO-BE scenario. The TO-BE scenario proves that the developed technology products are operational and that they answer user's requirements from technical and business points of view.

The TRL assessment, as presented in 1.1, is based on a survey where criteria associated to maturity topics have to be validated. A defined environment is associated to the TRL level studied.

For example, if the studied level is TRL4: The components and/or prototype have to be validated in a laboratory environment.

- ➔ The TO-BE scenario is composed of four components: the four technology products described in Table 1.
- ➔ The validation in laboratory environment consists in testing the components of the TO-BE process separately with simplified data: is the proof of usage of the four components verified and validated in a simplified Eurocopter environment?
- ➔ The simplified Eurocopter environment is characterized by simplified model of calculation, by simplified data and metadata.

The AS-IS and TO-BE scenarios provide evidence which validate the TRL criteria and survey.

Then, at TRL5, the proof of usage would focus on the entire TO-BE scenario with simplified data and, finally, at TRL6, the entire TO-BE scenario would be tested with real data.

5 CONCLUSION AND PERSPECTIVES

The article focuses on the technology transfer between research and Methods-Tools development projects (Remember Figure 2). Engineering technology products are studied during R&T projects and need to be transferred into M&T projects for their development. Engineering technology products as the Digital Mockup are used by engineers during aircraft development.

The article focuses on success conditions of the technology transfer. Indeed technology products present risks and uncertainties. The maturity assessment is a key success factor. The NASA TRL methodology is a tool that supports the maturity assessment. However it is developed only for aircraft but not for engineering technology products.

Maturity is not a sufficient condition for the success of the technology transfer. The proof of usage is proposed as a second key success factor. Future usage of engineering technology products has to be anticipated. The proof of usage improves the TRL methodology. Scenarios are used for assessing the proof of usage. Usage scenario contributes to understand the current and future way of working (the AS-IS and TO-BE scenarios). AS-IS and TO-BE scenarios were modeling under BPMN notation during the case study. By anticipating the context and conditions of usage, engineering technology products requirements are refined and validated thanks to the execution of the TO-BE scenario.

However a detailed theoretical framework should be developed in order to define rules, responsibilities and required items of a scenario. This theoretical framework will guide users to build scenarios. Furthermore, during the case study only one TO-BE scenario was associated to the AS-IS situation. But several TO-BE scenarios could be thought. They could be understood as steps for reaching an ideal scenario (Cornu 2012). In the case of several TO-BE scenarios, tools have to be proposed in order to compare and evaluate the best one. A perspective is to compare and evaluate functionalities of each TO-BE scenario as proposed by (Yannou 1999) in the frame of value analysis. Proposed tools have to be light and easy to use: studies are realized in R&T projects and uncertainties remain important.

The new approach aims to assess maturity, proofs of concept and usage of engineering technology products. But what is about financial aspects? It is well known in industry that budget is the development key. Proofs of concept and usage are key success factors for R&T to M&T technology transfer but are not sufficient.

An M&T project rests on the formalization of a business case that explains targeted savings of the project. M&T projects advantages are due to technology products integration. Therefore technology products have to prove their added-value. Scenarios illustrate at a small scale the usage of technology products. A perspective is to enrich the methodology with value assessment tool in order to anticipate and assess added-value of engineering technology products during R&T projects. Finally, the approach has to be enrich with the proof of value (Zimmer et al. 2012), composed by proofs of utility and of profitability.

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