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Development of a Methodology for Technology Demonstration Projects Evaluation

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Abstract

To ensure optimal resource allocation in technology demonstration projects, the evaluation of demonstrators of various maturity, scale, and nature has to be carried out. Most of the existing approaches focus on risk assessment or projected financial return; the need for a tool supporting multi-facet projects evaluation has been identified. This paper presents R2L framework based on three major criteria, defined in detail: Leap Potential, Learning, and Risk. The framework was applied to a real flight-test demonstrator project during workshops in a major aerospace company.

Keywords: *technology development, decision making, evaluation, risk management*

1. Introduction

Achieving and sustaining the leading positions in a rapidly changing competitive environment gets more and more challenging for many companies. Promising opportunities to gain a significant competitive advantage are connected to the development and employment of novel technologies offering product performance and features unobtainable with commoditized technologies. Yet new technology development is a time and resource-demanding process associated with uncertainties in technology performance, scaling up production, market acceptance, and others. Companies often choose to move gradually starting with the laboratory experiments, moving on to technology demonstration, and finally full-scale system design and development (Fevolden et at., 2017). Financial decisions are usually made correspondingly in a stepwise manner. Decision on whether to invest or not in proceeding with the phase of component/subsystem validation in a relevant environment is one of the most crucial decisions. Firstly, this phase itself requires notably bigger financial resources than the previous stages. And secondly, it is usually followed by the phase of full-scale system design and development. Taking into account that by the end of the conceptual design phase up to 70% of committed lifecycle costs are already defined (Walden et al., 2015), decisions on proceeding or not with the technology validation in a relevant environment are extra impactful.
The stage we are talking about is often called technology demonstration. Demonstration projects and trials are a crucial tool for companies to facilitate learning and reduce the risk associated with innovations (Fevolden et at., 2017). Evidence indicates that demonstration projects might fulfil multiple purposes, playing a specific role in supporting the transition of scientific activity towards commercialization (Moultrie, 2015). In energy systems, pilots and demonstration plants are key elements in helping to develop new technologies with the potential to address climate change challenges. Almost all authors highlight the importance of technology demonstration in facilitating learning and obtaining knowledge to be used later for the design of full-scale production systems and commercial products.

Within the boundaries of this research, the term "technology demonstration project" is similar to "demonstrator" and stands for a project devoted to the development of a functional piece of technology with the goal of proving its capabilities.

In an organizational context, financial resources are usually limited and it is often needed to select from several technology demonstration projects to ensure optimal resources allocation. Evaluation of the demonstrators is often made during special workshops. For such workshops, internal and external experts are often gathered together for a few hours or at most days. The expert panels are usually multidisciplinary, covering domains specific to the project. For example, in the case of some aerospace demonstrator workshop, those experts might include an experienced System Engineer, specializing in verification, technology demonstrator project manager/owner, a researcher on the related scientific topic (e.g. Specific type of fuel chemist), marketing expert, etc. Those experts often possess different amounts of knowledge on the projects and represent a variety of positions with various degrees of seniority. Such workshops are usually held in a concurrent, collocated environment, and are limited in timing ranging from hours to a few days at maximum. The number of demonstrators considered differs from a few to several dozens. Results of these workshops are further transferred to the top-level decision-making boards taking place once in several months. Based on the review from the decision-making board, approval, disapproval or proposal for further projects elaboration are received.

Even though different technology assessment approaches were developed through the last decades, almost no evidence of the easy-to-use framework specifically adapted for technology demonstration projects evaluation has been identified (section 2). Thus, the main research question formulated in this study is: "How can decision making in the technology development process be supported?". More specifically, this article aims to address two questions:

- RQ1: Which aspects of technology demonstration projects are necessary and sufficient for a comprehensive evaluation?
- RQ2: How should the evaluation process be organized to be informed while staying simple in use in the industrial context?

The framework and methodology were iteratively developed, tested and updated through a number of workshops in a large aerospace company looking for new systematic decision-making support tools.

The article outline follows the Design Research Methodology structure starting with the literature review (section 2), followed by research methodology and framework development process (section 3), framework description (section 4), case study (5) and conclusions (section 6).

2. Literature Review

The article reviews two strands of literature. The first strand includes studies on technology demonstration projects and their variety. As a result, the demonstrator definition that best fits this research is introduced. The second strand relates to the methods of demonstration projects evaluation.

2.1. Technology Demonstrators

When describing a technology development, several authors highlight the importance of the projects devoted to the demonstration of emerging technologies (Phaal et al., 2011; Moultrie, 2015). In one of the de facto standard tools in technology development, the Technology Readiness Level (TRL) framework (Mankins, 2009), developed by NASA to assess the 'maturity' of technologies, prototypes or demonstrators of one type or another are indicated as critical for progression from science to a marketable technology. Those demonstrators are described as embodiments of the technology at each stage, particularly between TRL 4 and TRL 7.

Phaal et al. (2011) refer to demonstrators as to "the particular milestones that delineate the various phases and transitions" meaning phases of the STAM (science, technology, application, market) technology development model introduced by him. In a broad sense, BenMahmoud-Jouini and Midler (2020) say that "demonstrators are a specific type of boundary objects that provide a shared language and serve as bridges between different worlds".

An internal diversity of the demonstrators is justified with the existence of the several classifications of demonstrators types introduced in the literature. Myers (1978) claims that it is necessary to distinguish

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between two types of demonstration projects: (1) experimental projects for "testing the workability of an innovation under operational conditions", and (2) exemplary projects "to demonstrate the utility of the innovation to potential adopters". Phaal et al. (2011) proposed seven different types of demonstrators that might be produced as technology moves towards the market, each aligned with the STAM phases. These include: supporting science and technology demonstrators, applied science and technology (feasibility) demonstrators, technology demonstrators, application demonstrators, commercial application demonstrators, price-performance market demonstrators, and mass-market demonstrators.

Within the boundaries of this research and from this point further, by term demonstrator we mean a project devoted to the development of a functional piece of technology with the goal of showing its capabilities. For example, in the case of the aerospace industry, methods to demonstrate the technological capability might include flight research, simulation/modelling, or wind tunnel tests. In this research, the term "technology demonstration project" is equal to demonstrator and comprises all the types introduced above. We would like to highlight that by demonstrator, we also mean a project and thus as any project, a demonstrator is characterized by a certain scope, timing, and budget.

2.2. Technology Evaluation Methodologies

Despite the wide spectrum of studies conducted on the decision making and technology assessment, not much evidence about methodologies targeting particularly technology demonstration projects evaluation has been found. The topic falls in the intersection of the two groups of reviewed methods. The first group includes methods and frameworks focused specifically on technology assessment and thus provides important guidance and inspiration into the criteria relevant for the demonstrator evaluation. The second group of methods supports the decision-making process itself by regulating organizational aspects of experts' opinions elicitation techniques and data processing from a mathematical point of view.

Decisions on the technology demonstration projects are often made based on certain decision criteria. There are many studies indicating a variety of possible criteria to be considered, as presented by Cooper (2001), Crawford and Benedetto (2006), and Moenaert et al. (2010).

Most of the recent advancements in the field, focus on risk and uncertainty quantification. Risk is measured both indirectly, for example, through TRL (Mankins, 2009) or directly, for instance, as a function of system architecture (Garg et al., 2017). Mohagheghi et al. (2017) proposed a model for R&D projects evaluation including a new risk-return index by utilizing interval type-2 fuzzy sets (IT2FSs). Mousavi et al. (2021) defined a novel risk-based fuzzy VIKOR (R-VIKOR) methodology to classify and rank the existing critical risk factors of NPD projects. Studies are also actively being conducted on project's portfolio risk assessment (Bai et al., 2021).

Much less work is done on quantifying benefits and opportunities provided by the developed technology. Only a few attempts have been made to quantify benefits and potential of adopting a new technology, for instance, Technology Need Value metric (Mankins, 2009).

In search of a comprehensive structured approach featuring both advantages and disadvantages of the particular technology, several approaches from distant domains were considered. The subject of this research has been strongly inspired by the industrial problem, which lies outside of the boundaries of one particular research domain and more likely is related to the intersection of several knowledge domains: systems engineering, technology management, decision making, and project management. The roadmapping approach (Phaal et al., 2011) is widely used in technology management, though it is not defining a particular methodology or support tool for the decision-making. SWOT (Sammut-Bonnici and Galea 2015) analysis is a famous instrument in project management, yet it is most useful for already functioning commercial projects generating a profit and doesn't take into account the projected value to be brought by the demonstrator later.

One of the frameworks most relevant to our research is called the "X-factor" and was developed by NASA (2012). The "X-factor" provides a quantitative measurement of a Program difficulty based on the multiplication of the following parameters: Discovery, Complexity and National benefit. However, the "X-factor" rating refers only to aircraft programs and is intentionally tailored to the context and requirements of the one particular government-funded organization. Our research is not focused only

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on aerospace and the need to extend the research to other companies and industries was identified. Moreover the “X-factor” does not define the decision-making process.

A number of quantitative methods have been applied, if not directly to technology demonstration projects, but to the related topics of technology transfer. For example, a fuzzy logic method has been utilized by Ordoobadi (2008) for the selection of advanced technology for adoption. The Delphi method and the fuzzy DEMATEL have been applied to identify barriers in university technology transfer (Quiñones et al., 2020). The real options valuation was employed in the context of prioritizing advanced technologies for NASA funding (Shishko et al., 2002).

In spite of an abundance of quantitative approaches, decision-makers appear to more readily use simple visual approaches to support collaborative decision making, e.g., bubble diagrams/ portfolio matrices (Cooper, 2001) or roadmaps and scoring models according to Oliveira et al. (2014). Our own experience has proven the same opinion which would be described in the use case section later.

Two popular methods which we investigated deeper were the Analytic Hierarchy Process (AHP) (Forman and Gass, 2001), and the Delphi method. AHP relies on a pairwise comparison of the objects with respect to each criterion. It should be notes that eventually, the AHP method was rejected based on the results of the industrial workshop discussed in section 4. Delphi (Skinner, 2015) on the other hand is a structured communication technique to reach consensus. The main Delphi features include:

- The anonymity of participants that helps to reduce the influences of individuals in authority, and group pressure for conformity, which often is a concern during other group-based processes in a concurrent, collocated environment.
- The iterative organization of process which allows experts to refine their responses during the rounds.
- Feedback between rounds of a survey which enables experts to explain and share their opinion.

The Delphi approach has been chosen in this research to structure the experts opinions collection process as addressing exactly the type of context we described in the introduction.

Our selection of the reviewed methods by no means attempts to cover all the spectrum of published works; nevertheless it provides an appropriate sample of studies proving that no decision support tool considering the multi-facet nature of demonstrators, while defining a coherent process of evaluation, has been identified.

3. Framework and Methodology Development Process

The Design Research Methodology (DRM) proposed by Blessing and Chakrabarti (2009) was used as the main reference for this research. The Research Clarification (RC) phase is represented by a literature review. The Descriptive Study I (DS-I) has been supported by the on-site workshop at the industrial partner CTO office and resulted in a deep understanding of the problem. During a Prescriptive Study (PS) phase, the proposed framework draft has been synthesized. Then this draft has been applied and reviewed during a couple of workshops in an iterative manner. These cycles correspond to the PS - DS-II feedback loops. Figure 1 represents the framework development process with workshops and their inputs/outputs mapped to the corresponding Research Stages of the DRM.

In the first instance, we developed a demonstrator evaluation framework prototype based on the literature research and our initial understanding of the problem. Subsequently, the content was reviewed in three dedicated workshops involving key staff within a major aerospace corporation. Three whole day workshops were run spaced apart by about 4 months. Participants included 4 researchers from our home institution and 3 to 4 representatives of the industrial partner CTO office possessing deep expertise in the field of demonstrators' assessment.

The primary goal of the first workshop was to develop a common ground and understanding of the problem statement, the industrial context and the main terminology. Then a set of framework design options were formulated and compared during the second workshop.

An example of such a design option was a choice of the type of output evaluation results from the support tool we developed. The output could be provided in either ordinal ("Project A is preferable to Project B") or cardinal ("Project A is assigned with X on the criteria one") style. In order to choose the most suitable style, the AHP method relying on pairwise comparison of alternatives was tested during

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the second workshop. Experience has shown that it takes an unreasonably long time for all experts to satisfy a consistency requirement. The number of comparisons is n(n-1)/2, with n as the number of objects to be pairwise compared, is growing nonlinearly and, in the case of, for example, 6 projects, would require 15 comparisons per each criterion. Hence, AHP has not been included in the final version of the proposed methodology. The Delphi method was eventually employed to support the consensus-based decisions on evaluation scores to be reached within a reasonable time.
Another design option defined whether a criterion set should be fixed or selected for each demonstrator evaluation session/company/industry. To approach the topic two demonstrators of a different nature were briefly evaluated. Results have shown considerable differences, in which the selected criteria played a vital role even for two projects from the same organization and industry.

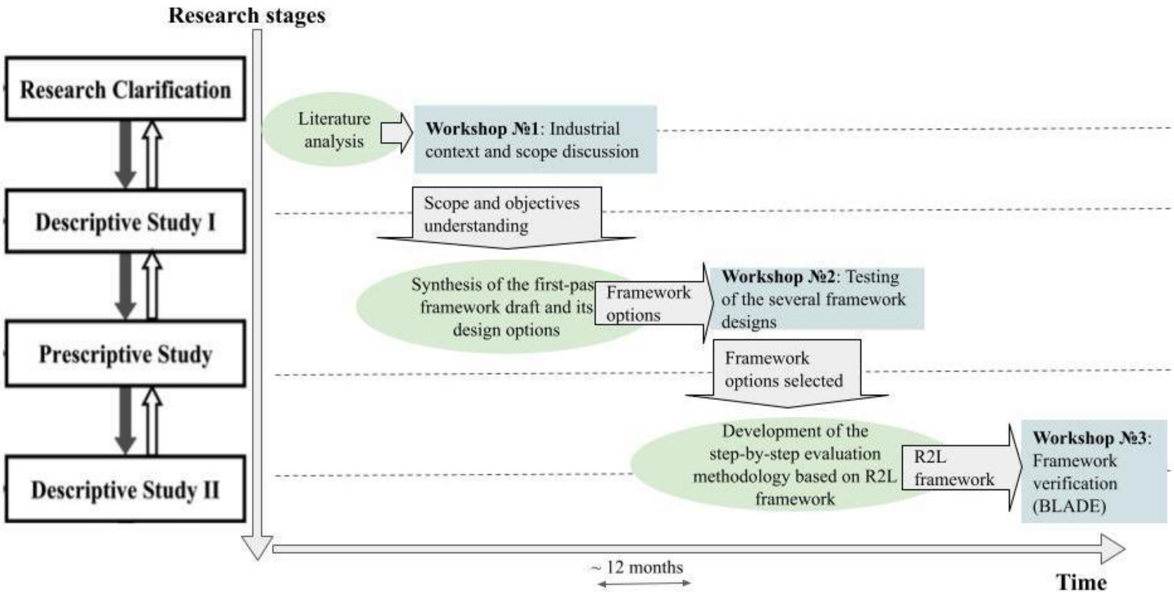

Figure 1. Framework development process

Thus, it was decided that a criteria selection step needs to be added to the methodology in order for it to be adjustable for different organizations.
Other design options touched the next questions: "To which extent the final results should be aggregated?" (a single score per demonstrator/set of scores); "How should all the scoring scales for each criterion be normalized?" (by comparing the considered project to the "ideal" Demonstrator/by providing detailed descriptions for each score); "Should the criteria be weighted?"; "How can we ensure the informed consensus to be achieved in a short period of a concurrent session?"
During the third industrial workshop, a detailed proposed step-by-step methodology has been verified by application to the real demonstrator evaluation with the relevant multidisciplinary experts. The resulting methodology was found to be promising for industrial application.

4. Description of the Proposed R2L Framework and Supporting Methodology

The main contribution of this research is divided into two parts: the R2L framework and the supporting evaluation methodology. The R2L framework defines the main criteria used for demonstrator analysis and provides detailed scoring instructions. The supporting methodology describes the evaluation process itself.

4.1. Leap Learning Risk(R2L) Demonstrator Evaluation Framework

Leap Learning Risk (R2L, read as "ritual") demonstrator evaluation framework proposed in this paper is built upon the three major components or criteria: Leap Potential, Learning and Risk.

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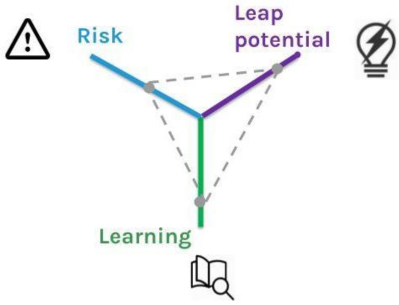

Figure 2. Visually represented summary of R2L

Leap Potential represents the ambitions of the demonstrated technology to propose significant competitive advantages in the future. Leap potential is indicating the size of the commercial opportunity. This component represents the size of the competitive advantage enabled by the technology improvement. It also incorporates possible synergetic effects for several future products employing the technology. Accomplishing the technology demonstration project can contribute to the assets of the company directly or can help external company clients to unlock the value of their products.
Learning criteria specifies how much the company would learn from developing a demonstrator. Demonstrator can contribute to the development of both knowledge and skills. Learning can take different forms from the development of the new tools and engineering models to the improvement of workforce performance including the accumulation of new know-hows. Learning also depends on a number of the required system modifications. Another contributing factor is the number of unexpected emergencies which are possible to catch up through the demonstrator operations.
De-risk is an aggregated risk metric of building the demonstrator. It is intentionally named "De-risk" instead of Risk to reflect that it uses an inverted scale - the higher is the score of the considered demonstrator the less risk it involves. Aspects contributing to overall project riskiness include complexity, need for integration, technological and manufacturing maturity and others.

Table 1. Summary of R2L

Leap Potential = function (benefits from using future technology)
Learning = function (new tools, knowledge, skills, system modifications accumulated)
De-risk = function (complexity, integration, maturity, etc.)

Table 2. R2L detailed scoring instructions

	Low	Medium	High
Leap Potential	Demonstrator presents a moderate efficiency raise for existing products.	Demonstrator enables new functionality in the products or strongly improves existing products' performance.	Demonstrator unlocks the opportunity for a new industry/business for possessing company.
Learning	No analysis or system model changes required e.g., integration of a new component.	Moderate changes in instrumentation are necessary e.g. addition of a new subsystem to the existing aircraft.	New simulation models and analysis are required for performance prediction
De-risk (note inverted scale)	Significant risk. Multi-disciplinary complex demonstrator. Technology subparts are strongly interacting or are immature.	Moderate risk. Demonstrated technology requires is highly integrated, multi-disciplinary.	Minimal risk. Well-known approach.

4.2. Supporting Methodology

To receive a demonstrator profile as illustrated in Figure 2, the supporting methodology defining processes on several levels was developed. Figure 3 shows the main elements of the methodology and Table 3 describes it in more details. The methodology starts with a Step 1, where the top 10 criteria are selected from a bigger list to adapt the methodology to a particular company and industry. At Step 2.1,

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each of the demonstrators is assessed based on the selected criteria to ensure a comprehensive investigation. And finally, the R2L is applied. We suggest different people to be involved in the criteria selection and demonstrator evaluation processes to avoid bias. For all steps, we advise usage of Delphi opinion elicitation technique.

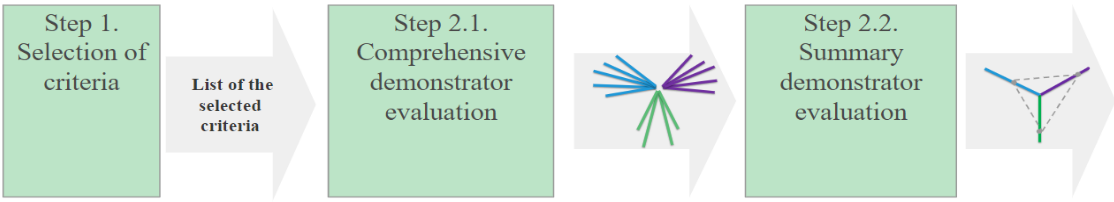

Figure 3. R2L supporting methodology

Table 3. Details of the supporting methodology

	Step 1. Criteria selection	Step 2. Demonstrator evaluation 2.1 Comprehensive evaluation	 2.2 Summary evaluation
Criteria	Extensive list of criteria adapted to the particular industry and organization	10 top criteria from the previous step	Leap Learning Risk
Method	Delphi	Delphi	Delphi
How many time accomplished	Once, during framework localization procedure	For each demonstrator	For each demonstrator
Step output	Set of criteria specific for company/industry	Comprehensive demonstrators profiles	R2L demonstrators profiles

4.3. Results of the R2L and Supporting Methodology Application

Results of the R2L framework and methodology application are then transferred to the decision-making board. Output results consist of three components:

- R2L projects profiles.
- Detailed protocols of the evaluation process including anonymized data on the outcomes of each round undertaken before the consensus has been achieved.
- Projects related information such as budget required, timing, performance enhancement.

5. Case study

5.1. BLADE Demonstrator Project Description

R2L framework and methodology were applied to evaluate the demonstrator project called BLADE which stands for “Breakthrough Laminar Aircraft Demonstrator in Europe”. The project aimed to improve aviation’s ecological footprint by allowing a 50% reduction of wing friction and up to 5% $CO2$ emission. It was the first test aircraft in the world combining a transonic laminar wing profile with a standard aircraft internal primary structure. A co-located workshop was conducted with the participation of the senior and middle management of the major aerospace company. There were five experts in the panel, which were selected for the concurrent co-located session: four professionals managing the demonstrator projects and people empowered in the budget decision-making with at least 15 years expertise in industry.

5.2. Methodology Parameters

The Delphi method was applied to reach the consensus at all steps. Parametric statistical method, coefficient of variation (CV) which stands for the standard deviation divided be the sample mean value, was used as a termination criterion:

$$CV = \frac{\delta}{\bar{x}} \qquad (1)$$

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The value of CV = 0.5 has been selected to identify the need for an additional round to be conducted. To keep anonymity, an online tool developed by our research group was used to collect the data.

5.3. Step 1: Criteria Selection

Ten out of fourteen criteria have been selected as the most important criteria. They included: opportunity generation", "demonstrator "NPV"- Net Present Value, "TRL", "Complexity", "Roadmaps connection", "Safety", "MRL"- Manufacturing Readiness Level, "Generated IP", "Environmental Impact" (listed starting by the most popular criteria). "Technological "know-how"", "Government regulations", "Marketing" and "Availability of experts in-house" were considered less important and were not included in the final set.

5.4. Step 2.1: Demonstrator Project Evaluation

The BLADE project was then assessed based on the top 10 criteria selected in Step 1. Results of the first round of anonymous voting are represented in Figure 4. Three criteria: Safety, Environmental Impact and Roadmaps connection are underlined in orange colour. The coefficient of variation (CV) on those criteria has been more than 0.5 after the first round. This inherently meant that there were two or more clusters of opinions prevailing in the expert panel.

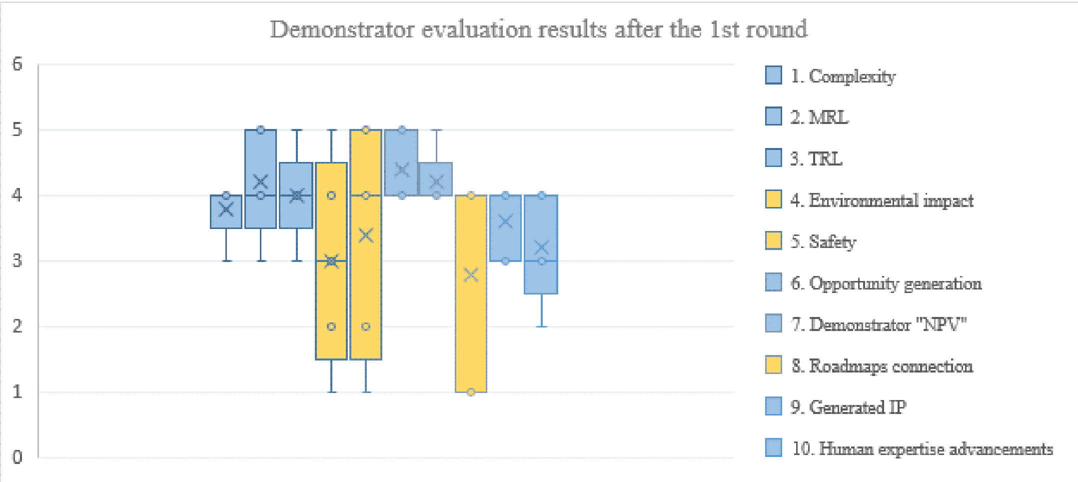

Figure 4. R2L supporting methodology

In order to reach convergence, the panellists were shown Figure 4 and were given an option to share their opinion on the controversial criteria anonymously. After a short opinion exchange, the next round was undertaken. In the second Delphi round, the group converged on the debatable criteria satisfying the termination criteria or in other terms - reached a consensus.

5.5. Step 2.2: Summary Evaluation - R2L

Finally, the BLADE project was evaluated based on the R2L metrics. The resulting project profile is shown in Figure 5. The profile of the BLADE project gives a multi facet overview of its strengths and weaknesses. The overall evaluation process was conducted during the third industrial full day workshop and took about 2 hours to complete including discussion.

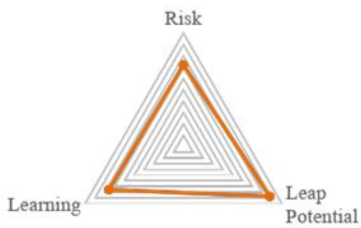

Figure 5. BLADE demonstrator R2L summary evaluation result

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6. Conclusions

Our study resulted into the Leap Learning Risk (R2L) framework and supporting methodology offering a comprehensive yet simple to apply tool for the evaluation of technology demonstration projects. The framework has been developed and verified in an iterative manner during a series of workshops with an industrial partner.

The research questions have been successfully addressed. The demonstrator evaluation has been chosen as the most critical phase from a decision-making point of view. R2L provides a balanced set of criteria covering the most important demonstrator related aspects of different nature: Leap Potential, Learning and Risk, answering the first research question about necessary and sufficient demonstrator evaluation criteria. Detailed scoring instructions were introduced to unify the process. And the methodology, relying on anonymous Delphi opinion elicitation technique in the first round, facilitates consensus achievement targeting the second research question. Final evaluation results presented in the visual spider diagram form allow easily analyse the several demonstrators at a given session and respectively make decisions about project portfolio formation. Application of the R2L framework to the BLADE demonstrator project met the expectations of the industrial representatives.

The novelty of this research lies in proposing a tool emphasizing benefits and learning gained from pursuing a certain technology along with the risks. This is consistent with the recent studies. For example, Noh et al. (2020) proposed the opportunity driven approach for technology roadmapping. The R2L major criteria somehow correlate with the criteria proposed by Ravari et al. (2016), proving a need for the multi-facetted approach to demonstrators.

A possible research limitation can be caused by the fact that the authors developed the list of criteria mostly based on the literature review. The conducted case study was extensive and involved relevant experts, but these lists may not be complete when compared to frameworks adopted by other companies, and so it may be important to review and customize the lists.

Future research can be seen into two directions. First of all, further R2L application at a biomedical Venture Capital company is already in process at the moment of paper submission and data should be available in the near future. Testing R2L in more case studies in different industries from aerospace, IT, robotics to pharmaceuticals is important to establish the framework relevance, efficiency and limits of applicability. Initially developed for the corporate demonstrator evaluation setting, the R2L framework and methodology are potentially applicable to a wider range of contexts: from venture capital companies to government funded research programs.

Another future research direction is motivated by the observation of the absence of a metric to quantify the developed technology potential in terms of being infused in a large number of products. The special metric measured using a Design Structured Matrix (DSM) including technology demonstrators, products and PSS is currently being developed by the authors.

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