DEVELOPING A TECHNOLOGY READINESS ASSESSMENT METHODOLOGY FOR AN ENERGY COMPANY

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ABSTRACT

Petrobras, a Brazilian energy company, funds many universities and R&D institutions and performs internal R&D projects with high level of innovation. It is a challenge to effectively manage an R&D portfolio that has more than 800 projects, at different maturity levels, so a Technology Readiness Assessment (TRA) methodology is an important tool to support technology management. The Chemical Industry Information System (SIQUIM), a group actively involved in technology and innovation management from the Chemical School of the Federal University of Rio de Janeiro, was invited to develop methodology with Petrobras. A task force was created to reach this goal, taking into consideration, as a reference, the TRA guide G 413.3-4A by the U.S. Department of Energy (DoE). It was decided to keep the same concepts, process model and technology readiness levels of this original methodology, in order to preserve comparability.

Petrobras selected four projects within its areas of knowledge, at distinct readiness levels, taking into account the different business cultures within areas, to be used as pilot projects for the development of the Petrobras TRA methodology, in a one-year timeframe, and considering the original DoE methodology as background. The new managing tool to be created should be suitable, effective and easy to apply in the Energy and Oil & Gas environment, using the existent technical and business jargon of the company.

A Peer Reviewer, TRA Team and its leader were nominated for each project. A survey about TRA methodologies and implementation experiences available in the specialized literature was conducted, as well as a visit to a company, which had already developed its own TRA managing system. The adaptation and fit of the methodology to the energy business environment was performed, and the four projects were evaluated using this new tool.

The deliverable of the work was Petrobras' TRA Methodology, which encompasses two versions of the Technology Readiness Level Calculator spreadsheet: a full version for the most critical, strategic and resources demanding projects, and a simplified version for appraising the regular projects of this large project portfolio.

Key words: technology readiness assessment (TRA)**,** technology readiness level**,** R&D management, innovation management, oil & gas companies

INTRODUCTION

Petrobras, the Brazilian energy company, was founded in 1953 with the purpose of developing activities in the oil & gas and derivatives sector, aiming at supplying the national market. It is now one of the leading oil companies in the world, with US$ 140 billion net revenue in 2013, a production of 2.5 billion barrels of oil equivalent per day, a work force of 86,000 employees, and presence in 17 countries. (Petrobras, 2014)

In order to expand its operations and reach its present position, Petrobras has always counted on novel technologies. In the beginning, the main objective was to adapt refining technologies, but oil discoveries in deep-water fields changed the technology development activity that focused on exploiting these large oil reservoirs.

Technology development is, therefore, an essential drive for the company's competitiveness and to accomplish the company's business strategies. R&D projects are either developed internally or with partners, sometimes using open innovation practices and involving actors like universities, R&D institutes, suppliers and other oil companies. The innovation activities are coordinated by the Research and Development Center Leopoldo Américo Miguez de Mello (CENPES), Petrobras' R&D organization (Parreiras et al, 2013). Such complex development environment requires management skills for efficient planning and good tools for the execution and control of the project portfolio.

Besides these internal developments, the acquisition and application of technological solutions that are available in the market have always been considered. When suppliers and solutions are known, the decision of developing its own or acquiring external technology can be taken with less risk than for novel technologies that haven't been commercially proven.

Petrobras has some technology needs in multiple and alternative technology paths, from off-the-shelf to embryonic solutions. To increase the effectiveness of planning, executing and controlling R&D activities, as well as reduce the risk of acquiring technologies and becoming more predictable in the technology development timeframe, it is worth to be able to count on a precise tool to appraise the readiness of technological solutions.

This appraisal should help to better know and mitigate the technological risks of a given technology solution. Moreover, it should better estimate the time-to-market of a novel technology and, thus, support the R&D management decision making.

PETROBRAS' R&D ACTIVITIES

Areas of knowledge & Technological Programs

Technology management at Petrobras is coordinated by CENPES, organized into areas that correspond to the company's business areas: Exploration, Production, Downstream, Gas Energy, and

Renewable products and biofuels. The Basic Engineering group is located at the same site in order to increase the synergy with the R&D group and to speed up the implementation of innovations. A workforce of about 2,000 employees is responsible for developing and supporting R&D and Basic Engineering activities. Nowadays the R&D portfolio has over 800 projects in several stages of maturity. This portfolio is segmented into specific R&D portfolios, called technological program and technological knowledge area. The first one is multidisciplinary, basically business-oriented and has a specific execution timeframe. The latter is disciplinary and has a long-term course.

Petrobras' Technology System and its governance

Technology development planning is based on two main inputs: the strategic planning and business area plans, and the technology-monitoring insights, which consider signals, trends and the future vision emerging from the technology development players. A structure of committees is responsible for deploying these two inputs and establishing the guidelines for the project level using a top-down process. To establish the right technological focuses, the Executive Manager of each business area identifies the technological challenges that need to be addressed for each business objective, and a group of technological targets is determined. The challenges and its targets are then grouped into distinct programs and knowledge areas, and for each portfolio, the group of projects is revised by General Managers, that is, at a lower managing level. The projects are then planned and executed by specialists. The governance of the process is shared between each business area and the corresponding R&D counterpart at CENPES.

According to Almeida (2005), the Technological System of Petrobras is responsible for the shared management of the activities carried out by distinct areas of the company that are involved in research, development, operational improvement, and application of technologies in the core business activities. CENPES is responsible for the coordination of the technology development actions among the different company actors.

Due to the regulations applicable to oil and gas exploitation in Brazil under the regime of concession contracts, Petrobras has to invest 1% of the gross income from some of its oil fields in R&D projects, and at least half of this value must be invested in university labs and non-profit R&D institutions, resulting in a large group of projects being carried out by Brazilian partners.

TRA METHODOLOGY

The Technology Readiness Assessment methodology is a process to determine the maturity of a technology by means of documented evidence. It provides a snapshot (status) of the maturity of a given technology development and the degree of advancement for insertion in the production environment, considering three important aspects, the robustness of the technical scope, time-to-market, and the cost of implementation to guide the decision for its implementation.

The origin of the methodology is (DoE, 2011):

- NASA (first use in the 1980s) and DoD - Department of Defense of the United States. The AFRL - Air Force Research Laboratory developed a spreadsheet for measuring TRL;
- DoE - Department of Energy generated a customized methodology: DoE G 413.3-4A, on 15.09.2011.

The TRA methodology is based on nine levels of maturity, that is, nine technology readiness levels (TRL). It has well-defined evaluation criteria for each level, it identifies the Critical Elements of Technology (ECT), and the assessment is performed based on a consolidated documentation. It also searches impartiality through adopting independent auditors. The description of maturity levels is shown in Table 1.

The application of the TRA process model to an R&D project consists of three sequential steps:

- Identifying the Critical Technology Elements;
- Assessing the Technology Readiness Level;
- Developing a Technology Maturation Plan.

The last step isn't included in the scope of this work. The second step is carried out using the TRL Calculator, which is a Microsoft Excel spreadsheet application that allows the user to answer a series of questions about the technology project. Once the questions have been answered, the calculator displays the TRL achieved.

Table 1: Technology Readiness Levels (Source: DoE, 2009)

Relative Level of Technology Development	Technology Readiness Level	TRL Definition	Description
System Operations	TRL 9	Actual system operated over the full range of expected mission conditions.	Actual operation of the technology in its final form, under the full range of operating conditions. Examples include using the actual system with the full range of wastes
System Commissioning	TRL 8	Actual system completed and qualified through test and demonstration.	The technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental testing and evaluation of the system with actual waste in hot commissioning.
	TRL 7	Full-scale, similar (prototypical) systemdemonstrated in relevant environment	Prototype full scale system. It represents a major step up from TRL 6, requiring demonstration of a relevant environment. Examples include testing the prototype in the field with a range of simulants and/or real waste and cold commissioning.

Relative Level of Technology Development	Technology Readiness Level	TRL Definition	Description
Technology Demonstration	TRL 6	Engineering/pilot-scale, similar (prototypical) system validation in relevant environment	Representative engineering scale models or prototypes system, which is well beyond the lab scale tested for TRL5, is tested in a relevant environment. It represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype with real waste and a range of simulants.
Technology Development	TRL 5	Laboratory scale, similar system validation in relevant environment	The basic technological components are integrated so that the system configuration is similar to (matches) the final application in almost all respects. Examples include testing a high-fidelity system in a simulated environment and/or with a range of real waste and simulants.
Technology Development	TRL 4	Component and/or system validation in laboratory environment	Basic technological components are integrated to establish that the pieces will work together. This is relatively "low fidelity" compared with the eventual system. Examples include integration of "ad hoc" hardware in a laboratory and testing with a range of stimulants.
Research to Prove Feasibility	TRL 3	Analytical and experimental critical function and/or characteristic proof of concept	Active research and development (R&D) is initiated. This includes analytical studies and laboratory-scale studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative tested with simulants.
Research to Prove Feasibility	TRL 2	Technology concept and/or application formulated	Inventions begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are still limited to analytic studies.
Basic Technology Research	TRL 1	Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development (R&D). Examples might include paper studies of a technology's basic properties.

According to the DoE (2011) the benefits of applying the TRA methodology are:

- The process of Technological Readiness Assessment (TRA) uses a structured methodology with clear criteria and based on consistent documentation (reports of R & D projects);
- The process also helps the identification of specific actions to reduce the risk of the project, facilitates the comparison of candidate technologies, promotes discipline in decision making, and improves technical communication.

Project evaluation, using the TRA methodology, is performed by the aforementioned TRL Calculator, fed by a TRA Team composed of professionals not directly involved in the project execution, and a peer reviewer, a technical expert also not involved in the project.

IMPLEMENTATION AT PETROBRAS

The TRA methodology developed by the DoE (2011) provides relevant basis for the maturity measuring of a technology development project in several industries, and was used as basic reference by the task force to create the Petrobras TRA methodology. Two premises were set for the development of this methodology: regardless of the adaptations or customizations made on the TRL calculator and the TRA methodology, the results obtained should be comparable to those obtained using the DoE scales, and a simplified version of the TRL calculator should be issued, adapted for fast appraisals, yet based on comparable criteria.

The Petrobras TRA methodology was developed by the team of Technology Management of CENPES and the Chemical Industry Information System (SIQUIM), a group actively involved in technology and innovation management from the Chemical School of the Federal University of Rio de Janeiro, and conducted in a one-year timeframe.

Awareness of the TRA methodology

The TRA guide from the U.S. Department of Energy - DoE G 413.3-4A was used as reference for generating the Petrobras methodology. While the guide was thoroughly analyzed, other sources of information were also used, and other previous experience references were considered, such as: D. Clausing & M. Homes, Technology Readiness, Research Technology Management, July-August 2010; N. Choucri, D. Goldsmith, T. Mezher, Modeling Renewable Energy Readiness: The UAE Context, MIT Open Access Articles, IEEE, 2011; Department of Defense, Technology Readiness Assessment Deskbook, July 2009, just to name a few.

Besides, a full-day visit to a Brazilian company which had already developed its own TRA managing system was made. The visit output was some good insights and warnings for the development of the work.

It was decided that the same concepts, process model and technology readiness levels of this existent methodology would be kept and adapted to the framework of an Oil & Gas company. Therefore, the maturity measurement result of a Petrobras R&D project could be compared, on an equal basis, to projects of other institutions.

Selection of the four Pilot Projects and their TRA team

The Petrobras R&D project portfolio has projects related to the company's several business areas, with distinct nature, structure and culture, as well as maturity levels. For the customization of the TRA methodology, four R&D projects were selected as pilots:

- one from the upstream area – Electrical submersible pump installed in a subsea skid;
- one from the downstream area – FCC catalyst for light olefins production;
- and two from cross-cutting areas: Nanotechnology – Nanocomposite material for coating of pipes, and Environmental Preservation – Optical fiber sensors for gas leakage detection.

In order to compose the TRA team, it was necessary to have technically qualified personnel not directly involved in the project execution. Another important actor was the Peer Reviewer, who had to be a senior professional with broad and consistent knowledge of the technologies developed and employed in the project; however, this expert should also be external to the project team. The TRA Team was composed of SIQUIM members, and the nominated Peer Reviewer of each project. Normally, these experts came from the client-side project, due to their technical knowledge of the specific projects.

Getting aware of the pilot projects

This step started in a meeting, in which information about the DoE TRA methodology was shown, such as objective, concepts, main characteristics and benefits of this managerial tool. The Technology Readiness Levels and its calculator were presented to the R&D project Coordinator and members. In addition, the Coordinator had to present the project highlights, which should include the following aspects: project motivation and objective, main targets, milestones and deliverables, parameters for measuring its completion, project schedule, resources and budget, expected benefits, steps of the evolution of the project and its current status. All technical and managerial documents of the project should be promptly released to the TRA Team, including the preliminary plan, technical and managerial reports, minutes of the meetings, contracts with third parties (partners and suppliers) and others piece of information related to R&D activities and its commercial implementation.

These ideal conditions for a fruitful and effective meeting weren't sometimes present and to fully accomplish the meeting objective some extra actions and additional meetings were required.

The TRA Team members read all documents and took notes of the main objectives and targets of the project, milestones and deliverables. Some unclear or vague points were written down in order to later clarify them with the Peer Reviewer and the R&D project Coordinator. Normally, the TRA Team Leader carefully read all documents and prepared a detailed presentation about the R&D project to the SIQUIM members and received input and comments from his colleagues.

Translation and customization of the methodology to the Petrobras' business environment

The translation and customization of the DoE TRA methodology was made, considering the business environment and some legacy and present managerial tools at Petrobras, such as:

- The decision gate model of the innovation pipeline;

- The Technology Research & Development process – Brief Guideline, which gives the guidelines for the different steps and deliverables of technology products, such as idea enrichment, pre-project, R&D project, basic engineering project, and troubleshooting & technical assistance services;
- Independent Project Analysis Methodology®;
- Project Management Institute Methodology®.

Consequently, a correlation between the TRL concepts and the Stage Gate model and Capital Project Managing tools needed to be done, taking into consideration the existing culture and technical jargon of the organization, as shown in Figure 1. As a result, an initial version of the Petrobras TRL calculator and adjustments to the TRA methodology were generated.

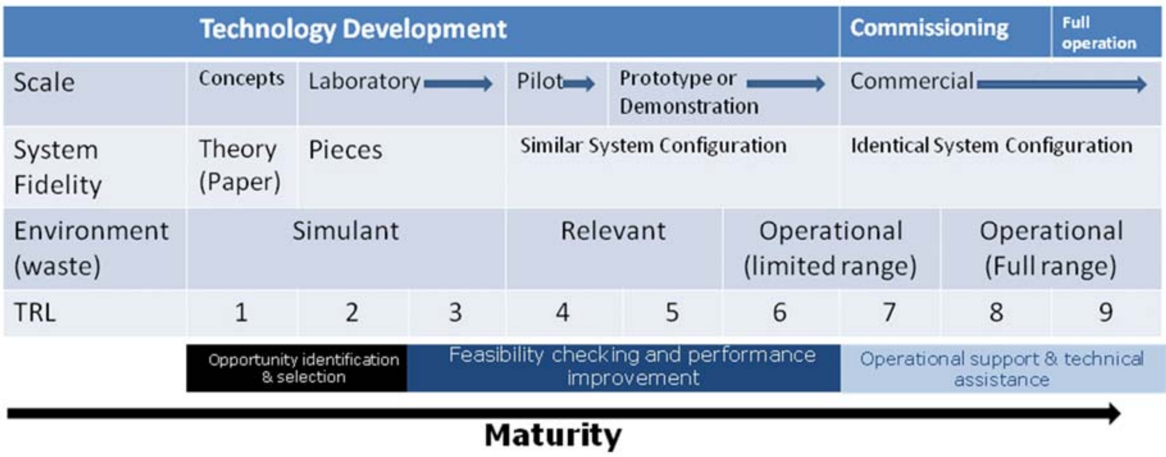


Figure 1: Technology Readiness Levels in Petrobras' jargon (adapted from DoE, 2014)

At the end of this step, the first version of the adapted TRA methodology was proposed.

Application of the first version to the Pilot Projects

After gathering the necessary information about the R&D project (objective, main targets, deliverables, etc.), the following step was to correctly define the project's Critical Technology Elements (CTEs). A technology element is "critical" if the system being acquired or developed depends on this technology element to meet operational requirements (with acceptable development cost and schedule, and acceptable production and operation costs) and if the technology element or its application is either new or novel, or in an area that poses major technological risk during design or demonstration (DoE, 2011). Once identified, the CTE must be validated using the "Criticality to Program Criteria" and the "New or Novel Criteria" checking templates.

The next step was to estimate the initial TRL and identify the documentation which supported this estimation. Then questions (criteria) related to the estimated TRL were answered and the support documents that validate the answer were identified. The pending documentation was listed for future checking.

The Peer Reviewer was then consulted for the validation of the CTE and helped identify or provide the lacking support documents. A Clarification Meeting was held between the R&D Project Team and the TRA Team, in which the preliminary TRL obtained for the project was presented, questions and doubts related to technical aspects were treated, and the pending documentation elucidated.

After solving the items related to pending documents and wiping out all questions and doubts about the project status, the TRA team was able to consolidate the TRL evaluation, and the Preliminary TRA Report was issued for each project. The main topics that should be part of this report were:

- Project objective and main targets;
- R&D Project team, including partners and suppliers;
- Project documentation analyzed;
- Identification of the project ECTs;
- Relevant aspects in relation to the evaluation process;
- TRL evaluation result;
- Recommendations for the R&D project progress.

The main steps of the TRL Evaluation process applied to the four Pilot Projects are in Figure 2.

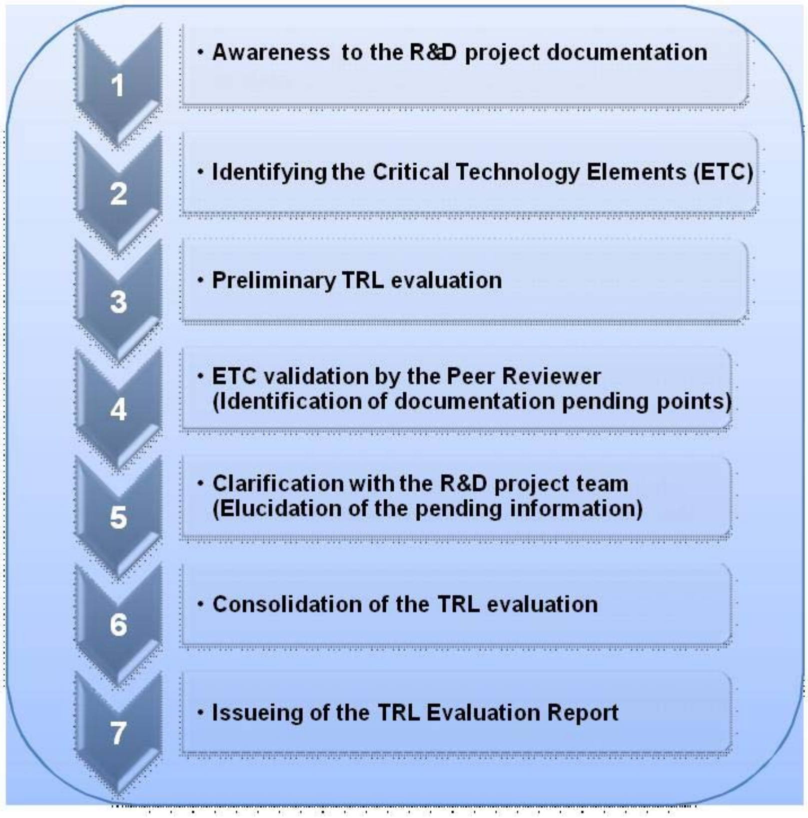


Figure 2: TRL Evaluation process steps

Consolidation of the methodology and upgraded version of the TRL Calculator

The SIQUIM team, based on the lessons learned through the practical application of the new methodology in the four Pilot Projects made many improvements, aiming at making this tool easier and friendly for the Petrobras' technical and managerial teams. Moreover, the rich experience acquired by the TRA Team in the methodology application and the knowledge generated by the participation of the Peer Reviewers were essential for the proposition of an upgraded second version of the Petrobras TRA methodology.

The consolidation was carried out looking for the convergence of many transversal items and the effective treating of the discrepant items, adapting and merging the evaluation criteria, aiming to get a robust, self-explanatory and simple methodology. Some original criteria considered non-relevant for the maturity evaluation of Petrobras projects were suppressed. For example, as previously mentioned, the origin of the TRA methodology was in the aerospace and aviation industry, for which the real test condition requires testing components or integrated-parts of the system in flying conditions. Since this is quite expensive, modeling and simulation tools are very useful and convenient from the early R&D stages. Generally, for the Oil & Gas industry, modeling and simulation tools are employed in more advanced stages, when the proof of concept has already been performed and the operational window better defined. Consequently, some criteria that considered modeling and simulation at early R&D steps were cancelled.

For the criteria selection of the more advanced maturity levels, TRL 8 and TRL 9, a senior Consultant was asked to check and commented on them. He had long experience in commercialization of new technologies, having worked at the Basic Engineering team of CENPES and possessing a background in commissioning, start-up, acceptance test, and performance monitoring of pioneer petrochemical and refining production units.

By the end of this step, 32 criteria had been modified and an upgraded TRL Calculator was created.

Generation of a simplified version of the TRL calculator

Petrobras has an extensive R&D portfolio, which encompasses a large number of projects. Therefore, a less time-consuming tool for measuring the maturity of projects can be very convenient. The full version can be applied for the most critical, strategic and resource-demanding projects, and a simplified version, for the appraisal of the regular projects of this large portfolio. The measured result of this simplified version isn't the actual TRL, since it can't be compared on the same basis, but a result that can give an idea of the maturity of the project, a "potential TRL". To generate this simplified TRL Calculator, the more critical and relevant criteria were considered and their selection was the output of teamwork after long discussions and consultations with experts.

Table 2 presents the methodology progress throughout the work, in relation to the number of criteria for each maturity level contained in the TRL Calculator.

Table 2: The number of criteria along the different versions of the TRL Calculator

TRL	Number of criteria of the 1st Version	Number of criteria of the Final Full Version	Number of criteria of the Simplified Version
TRL 1	9	7	3
TRL 2	21	15	5
TRL 3	23	16	4
TRL 4	28	25	5
TRL 5	28	21	4

TRL	Number of criteria of the 1st Version	Number of criteria of the Final Full Version	Number of criteria of the Simplified Version
TRL 6	33	27	5
TRL 7	17	16	4
TRL 8	16	16	3
TRL 9	8	8	2

Reevaluation of the TRL and the issuing of the Pilot Projects' TRA reports

After consolidating all evaluation criteria and getting an upgraded TRL Calculator version, the TRL of the four Pilot Projects were reevaluated, and the Final TRA Report for each Pilot Project was issued. The "potential TRL" was also calculated for each Pilot Project, aiming at checking the consistence of the simplified version of the TRL Calculator. The test results for all projects were coherent, demonstrating their consistency.

The upgraded TRA Report was sent to each Pilot Project team for comments, and a specific meeting was held to present the results and discuss and validate the project's final score. Both Excel spreadsheets, the full and simplified versions, of TRL Calculators were presented in the meeting for feedback for further improvements.

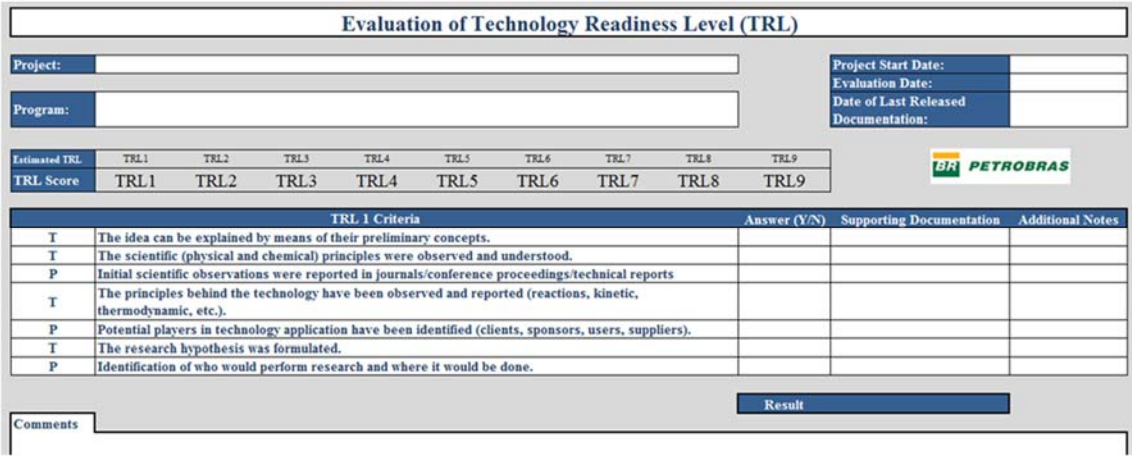
Generation of the Petrobras' TRA methodology

After the Pilot Project meetings and fruitful discussions and input from the Peer Reviewers and the R&D project teams, the four Final Pilot Project TRA Reports were published. These documents also contained recommendations for improvement and progress of the projects, mainly actions that needed to be taken in order to reach the next upper score.

The Petrobras TRA methodology document was also issued. This customized version included the following items:

- The objective and concepts of the TRA methodology and its scope;
- Critical Technology Elements identification method;
- Customized Full TRL spreadsheet;
- Customized Simplified TRL spreadsheet;
- Guidelines for the Project TRA Report.

The final versions of the TRL Calculators were also generated. These tools aim to offer a standardized and reproducible identification process of the TRL for any technology in development, making it possible its comparison with future technologies. The output of the TRL Calculator can support the decision-making process in critical managerial tasks, such as the selection and prioritization of projects, the acquisition of novel technology, and the greenlighting of projects. An Excel spreadsheet screen of the full version of the Petrobras TRL Calculator is shown in Figure 3. More specifically, the TRL 1 criteria are presented.


Evaluation of Technology Readiness Level (TRL)

Project:
Program:

Project Start Date:
Evaluation Date:
Date of Last Released Documentation:

Estimated TRL	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8	TRL9
TRL Score	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8	TRL9

	TRL 1 Criteria	Answer (Y/N)	Supporting Documentation	Additional Notes
T	The idea can be explained by means of their preliminary concepts.			
T	The scientific (physical and chemical) principles were observed and understood.			
P	Initial scientific observations were reported in journals/conference proceedings/technical reports			
T	The principles behind the technology have been observed and reported (reactions, kinetic, thermodynamic, etc.).			
P	Potential players in technology application have been identified (clients, sponsors, users, suppliers).			
T	The research hypothesis was formulated.			
P	Identification of who would perform research and where it would be done.			

Result

Comments

Figure 3: The screen of the full version of the Petrobras TRL Calculator for the TRL1

The sequential steps of the generation of the Petrobras TRA methodology are presented, in the Figure 4.

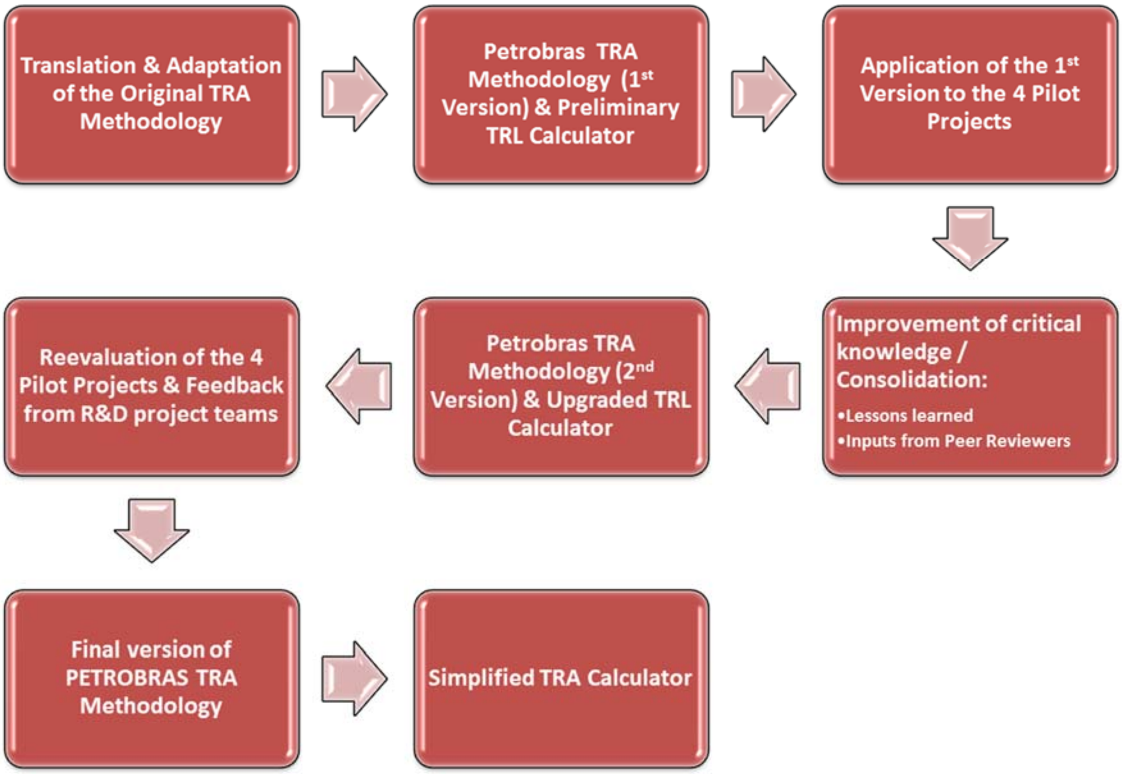


Figure 4: Process flow of the Petrobras TRA methodology

Wrap-up meeting and the Petrobras TRA methodology presentation

On September 30, 2013, a wrap-up meeting was held at CENPES and the output of the work was presented to the Petrobras staff. The outline of the TRA methodology, the path followed to generate the Petrobras TRA tool, and a demonstration of the TRL Calculator spreadsheets were also presented. A PowerPoint slideshow to guide the internal dissemination of the TRA methodology was also delivered.

CONCLUSIONS

The availability of a tool for measuring the maturity level of emerging technologies, developed by the company or by third parties, is very beneficial for an R&D organization, mainly if it provides a repeatable and standardized process that uses transparent and suitable criteria, and allows fair comparison between developing technologies. This kind of tool supports the company's decision-making process, being also helpful for the science and technology community.

By gauging technology since its lowest levels of maturity, it is possible to better predict when this novel technology may be delivered for implementation. Moreover, the tool also helps to identify the gaps in testing and demonstration, and unveils the main steps to reach the readiness level for the successful inclusion of the technological project.

The generation of a simplified tool to calculate the TRL by selecting the most essential criteria for the company was carefully performed. This quicker measuring tool represents an alternative in cases where a reduction of the complexity of the evaluation process is convenient.

The TRA methodology here described has several applications in the Petrobras' R&D managing processes, such as:

- Gauging a technology development and forecasting its time-to-market;
- Monitoring developments made by suppliers or partners;
- Assisting in technology acquisition (technology valuation);
- Comparing different technological routes and their evolving stages;
- Supporting the decision of developing technologies internally or externally;
- Identifying potential partners in technology development;
- Identifying technologies at risk that need more attention and management control or additional resources for development.

The task force work that generated the Petrobras TRA methodology focused mainly on determining a set of evaluation criteria that would better fit the company's peculiarities. Of course, as a managing tool, it should be upgraded through practice, and its fitness should be checked and improved from time to time. The implementation phase will start together with the revision of the R&D project decision gates throughout the first semester of 2015.

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