Lean R&D: An Agile Research and Development Approach for Digital Transformation

Marcos Kalinowski[1], Hélio Lopes[1], Alex Furtado Teixeira[2], Gabriel da Silva Cardoso[2], André Kuramoto[2], Bruno Itagyba[2], Solon Tarso Batista[1], Juliana Alves Pereira[1], Thuener Silva[1], Jorge Alam Warrak[2], Marcelo da Costa[2], Marinho Fischer[2], Cristiane Salgado[2], Bianca Teixeira[1], Jacques Chueke[1], Bruna Ferreira[1], Rodrigo Lima[1], Hugo Villamizar[1], André Brandão[1], Simone Barbosa[1], Marcus Poggi[1], Carlos Pelizaro[2], Deborah Lemes[2], Marcus Waltemberg[2], Odnei Lopes[2], Willer Goulart[2]

[1] Pontifical Catholic University of Rio de Janeiro (PUC-Rio), Rio de Janeiro, Brazil
{kalinowski, lopes, tarso, juliana, thuener, bianca, jacques, bruna, rodrigolima, hvillamizar, andre, simone, poggi}@exacta.inf.puc-rio.br
[2] Petrobras, Rio de Janeiro RJ, Brazil
{gscardoso, alex.teixeira, jawk, mceloscosta, marinhof, kuramoto, itagyba, cristiance.salgado, carlos.pelizaro, delemes, marcuswaltemberg, odnei, willer}@petrobras.com.br

Abstract. Petrobras is a large publicly-held company that operates in the oil, gas and energy industry. Recently, they conducted internal dynamics to identify several Digital Transformation (DT) opportunities to leverage their operational excellence. Addressing such opportunities typically requires Research and Development (R&D) uncertainties that could lead traditional R&D cooperation terms to be negotiated in years. However, there are time-to-market constraints for fast-paced deliveries to experiment solution options. With this in mind, they partnered up with PUC-Rio to establish a new DT initiative. The goal of this paper is to present the Lean R&D approach, tailored within this new initiative, and results of two case studies regarding its application in practice. We designed Lean R&D integrating the following building blocks: (i) Lean Inceptions, to allow stakeholders to jointly outline a Minimal Viable Product (MVP); (ii) early parallel technical feasibility assessment and conception phases, allowing to 'fail fast'; (iii) scrum-based development management; and (iv) strategically aligned continuous experimentation to test business hypotheses. In the two reported case studies, Lean R&D enabled addressing research-related uncertainties early and to efficiently deliver valuable MVPs within four months, showing itself suitable for supporting the DT initiative. Key success factors were the business strategy alignment, the defined roles and co-creation philosophy with strong integration between Petrobras and PUC-Rio's teams, and continuous support of a highly qualified research team. Main opportunities for improvement, based on our lessons learned, rely on better adapting Lean Inceptions to the DT context and on scaling the approach to a project portfolio level of abstraction.

Keywords: Digital Transformation, Agile Methods, Lean, Research and Development, Continuous Experimentation.

1 Introduction

Digital transformation can be seen as a process in which organizations investigate the use of digital technologies to innovate their way of operating, aiming to solve business problems and to achieve strategic goals. The resolution of such problems frequently involves transformations of key business operations that may affect organizational structures, processes, and products [1]. Organizations of almost all industries are conducting digital transformation initiatives to explore digital technologies and exploit their benefits [1].

Petrobras is a large publicly-held Brazilian company operating on an integrated basis and specializing in the oil, natural gas, and energy industry. Internal efforts, including the establishment of a new digital transformation board and initiatives within their main business areas, enabled them to identify several opportunities in which digital transformation could potentially help them to leverage their operational excellence.

Digital transformation and innovating business processes by using digital technologies typically involve Research and Development (R&D) efforts. CENPES is the research center of Petrobras, responsible for coordinating and conducting research initiatives. Such R&D initiatives commonly involve cooperation terms with research institutes and universities. These terms were usually designed in a plan-driven manner, with deliveries that, given research uncertainties, could take up to years. However, in the digital transformation context, there are time-to-market constraints and a need for fast-paced deliveries to experiment solution options.

To address these digital transformation needs, they partnered up with PUC-Rio to establish the ExACTa (Experimentation-based Agile Co-creation initiative for digital Transformation) initiative. With a different mindset from the previously established R&D cooperation terms, ExACTa was created to work with an open scope philosophy, following agile practices for R&D to enable focused and fast deliveries of Minimal Viable Products (MVPs) that can be used to test digital transformation business hypotheses. The ExACTa initiative was launched in September 2019, and the first step involved designing an R&D approach that would allow fast MVP deliveries. The resulting approach was called Lean R&D.

The Lean R&D approach relies on agile and continuous software engineering principles, including establishing a strong link between business and software development (BizDev) and continuous experimentation practices [2]. Based on these principles, we designed Lean R&D integrating the following building blocks: (i) Lean Inceptions [3], to allow stakeholders to jointly outline the vision of Minimal Viable Products (MVPs) that can be used to test business hypotheses; (ii) parallel technical feasibility assessment and conception phases, allowing solution options to 'fail fast'; (iii) scrum-based development management; and (iv) continuous experimentation, to test the business hypotheses in practice, allowing a build-measure-learn feedback cycle [4]. Moreover, the initiative counts on a dedicated research team, specialized in data science and machine learning, to support the development team with parallel investigation activities.

In previous work, reported in a short paper [5], we provided an overview of the first conceptualization of Lean R&D and initial (then, incomplete) experiences. The goal of this full industrial paper is to present Lean R&D in further detail and to report on detailed outcomes of two complete industrial case studies, including closing the feedback cycle with continuous experimentation. Hence, besides providing a more detailed description, we investigate Lean R&D's building blocks in much more detail, discussing the practical experience of applying it, highlighting observed industrial effects.

The herein detailed case studies concern applying Lean R&D in practice to build digital transformation enabling MVPs for two different business areas of Petrobras: industrial and logistics. In both cases, following the approach, valuable MVPs were delivered to stakeholders within a four-month timeframe. Continuous experimentation allowed to test business hypotheses in practice, supporting strategically aligned product increment planning. Throughout these case studies, Lean R&D showed itself suitable for supporting the digital transformation initiative. The business strategy alignment, the defined roles and co-creation philosophy with strong integration between Petrobras and PUC-Rio's teams, and the continuous support of a highly qualified research team, were observed as key success factors. Main opportunities for improvement, based on our lessons learned, rely on better adapting Lean Inceptions to the DT context and on scaling the approach to a project portfolio level of abstraction.

2 Background

Before designing Lean R&D, we tried to find a suitable agile approach that was, simultaneously: (i) digital transformation enabling (e.g., including strategies such as 'fail fast,' focusing on added business value and testing business hypotheses); and (ii) considering joint research and development activities to allow handling complex R&D projects (e.g., investigating and conceiving simulation models). Lean principles have been reported to offer the potential to improve the cost, quality, and speed of the R&D process [6]. However, we found no Lean R&D approach that was tailored for software product based, digital transformation enabling solutions. Lean Startup [7], for instance, inspired us with its business focus but does not consider our specific need to integrate R&D activities within agile methods to allow handling complex and research demanding software projects.

The following two subsections provide the background on continuous software engineering [2] and Lean Inceptions [3]. We used the expected dynamics of the first one to pursue our goal of narrowing the gap between business strategy, development, and experimenting solution options. Lean Inceptions, on the other hand, were used to help to align stakeholders to define digital transformation enabling and business strategy aligned MVPs.

2.1 Continuous Software Engineering

Fitzgerald and Stol [2], in their paper providing a roadmap and research agenda for continuous software engineering, argue that business, development, and operations should continuously be aligned with each other. Fig.1 provides an adapted and simplified representation of such alignment.

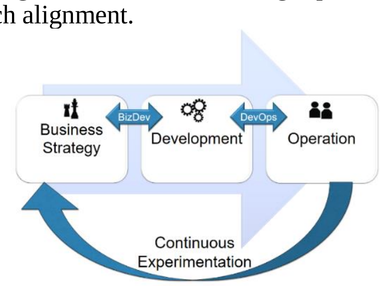


Fig. 1. Relations between business strategy, development, and operation. Adapted from [2].

The authors coin the term *BizDev* as the need to align the business strategy with the development of software [2]. *DevOps* represents the need to align the development of software with the deployment of that software into operation [8]. Finally, continuous experimentation focuses on conducting experiments with stakeholders consisting of repeated Build-Measure-Learn cycles [4][9].

Reflecting on the implications of these alignments in the context of engineering digital transformation enabling software products, *BizDev* and continuous experimentation play a key role in achieving digital transformation goals. After all, digital transformation commonly involves changes in key business operations that affect business processes and enabling products [1]. A focus on *BizDev* and continuous experimentation helps to enable assuring the development of a business strategy aligned product and to assess the added business value objectively. The importance of continuous experimentation within digital transformation contexts is also highlighted by Fagerholm *et al.* [4]. DevOps, on the other hand, represents a technical competitive advantage to speed up the development process.

2.2 Lean Inception

Lean Inception is defined by its creator as the "combination of Design Thinking and Lean Startup to decide the Minimum Viable Product (MVP)" [3]. It is a collaborative workshop that is intended to help stakeholders to jointly outline the vision of a valuable, feasible, and user-friendly MVP that can be used to test business hypotheses.

The steps involved in a Lean Inception are: defining the product vision; characterizing and scoping the product vision; describing personas; describing user journeys; conducting features brainstorming; conducting a business, technical, and UX review; sequencing of features; and finalizing the MVP canvas.

The final result of a Lean Inception is an MVP canvas, as shown in Fig. 2. Based on such canvas, the business hypotheses to be validated can be stated as "We believe that (*MVP name*) will be able to (*outcome statement*), we will know that this happened based on (*metrics for business hypotheses validation*)" [3].

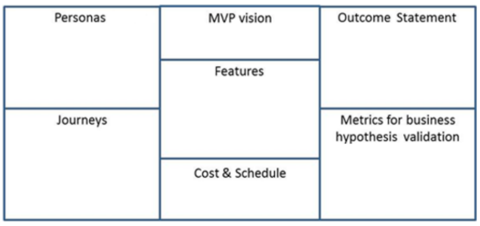


Fig. 2. Lean Inception MVP canvas. Adapted from [3].

3 The Lean R&D Approach

Our goal was to design an R&D approach for digital transformation, based on agile and continuous software engineering principles. CENPES and PUC-Rio's teams jointly brainstormed the following requirements as input for designing our approach.

R1: Maximize business 'value' while minimizing 'waste.' A fundamental focus of the lean philosophy is to shorten the time between a customer order and the delivery of that order, in such a way that any activities that do not add 'value' are considered 'waste' and removed [10]. To achieve this goal, there should be a focus on the business strategy and its alignment with development (*BizDev*) [2]. We address this main requirement in our approach by: (i) using Lean Inceptions involving representative stakeholders aiming at precisely defining the MVP that best fits the business strategy and focusing on the essential features to deliver business value; (ii) defining the business hypotheses since the beginning and applying continuous experimentation to validate them; (iii) having dedicated business owner representatives at each customer to help co-creating solutions that maximize business value; and (iii) going for agile and only essential documentation (e.g., agile requirements [11]).

R2: Allow to 'fail fast.' This involves employing the Lean Startup 'fail fast' concept [7], which enables handling opportunities and risks involved in experimenting with digital transformation solution options. The sooner you realize that an idea will not work, the faster you can update it or even replace it with a new idea. This requirement is addressed in our approach mainly by: (i) including 'fail fast' checkpoints; and (ii) including a technical feasibility assessment at the beginning of the process to cope with research-related uncertainties as soon as possible.

R3: Enable addressing complex problems. Digital transformation commonly involves applying cutting-edge digital technology to solve business problems in domains in which they were never applied before. Therefore, our approach considers the co-creation of solutions with domain experts from the customer side and continuous support from a qualified research team with a dedicated research team lead and experts in technologies that are commonly used within digital transformation contexts, such as data science and machine learning techniques.

3.1 Approach Overview

Based on the aforementioned requirements, we decided to design the approach using as building blocks Lean Inception, parallel (early) technical feasibility assessment and conception phases, scrum-based development management, and continuous experimentation. An overview of the designed approach is shown in Fig. 3.

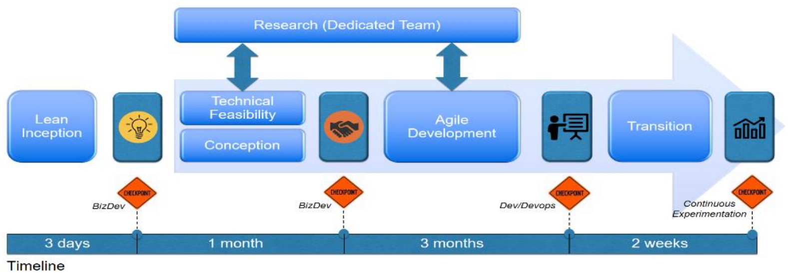


Fig. 3. Lean R&D approach. The timeline is illustrative and specific to our instantiation.

It is possible to observe four checkpoints, a set of activities, and support of a dedicated research team to technical solution related activities. Hereafter we describe the involved roles and activities.

Lean R&D Roles. The following roles are involved in the approach. To ease understanding, we provide examples of how these roles were distributed in the context of the ExACTa initiative.

Steering Committee. The main role of the steering committee is to assess the projects at the depicted checkpoints. This assessment aims at: (i) allowing the 'fail fast' of ideas that would not deliver the expected business value; and (ii) assuring that the approach is being used to address relevant innovation and digital transformation challenges. In our specific case, the steering committee for each project is composed by the coordinators of PUC-Rio's ExACTa initiative and managerial representatives of CENPES and Petrobras' target business area.

Project Manager (Scrum Master). Facilitates the Lean Inceptions and manages the agile research and development teams, assuring that the overall Lean R&D approach is being appropriately followed. In our specific case, we have one manager for four projects in parallel.

Product Owners (POs) and Business Owners (BOs). As in traditional Scrum, POs are responsible for maximizing the business value of the product resulting from the work of the development team. These POs are assisted by additional customer representatives BOs that work with the team to focus on the co-creation of solutions that maximize business value. In our specific setting, we have two POs handling two projects each and at least one BO per project.

Developers. The development teams. Currently, we have twelve full-time developers working in four projects (three per project).

Research team. The role of the research team is to support the development team in an early technical feasibility assessment and in complex tasks during development (e.g., investigating machine learning techniques to be used, elaborating prediction models). Currently, this team has one research lead supported by four researchers, serving four projects.

UX/UI design team. Responsible for designing user interaction mock-ups and high-fidelity prototypes to subsidize the front-end development. Currently, we have one UX/UI team lead and one UX/UI analyst, serving the four projects.

DevOps and infrastructure analyst. Responsible for providing the DevOps infrastructure to the development teams. Currently, we have one DevOps analyst serving four projects.

Lean R&D Activities. The approach starts with a *Lean Inception* to allow stakeholders to jointly outline the vision of an MVP that can be used to test business hypotheses. It is important to involve representatives of all relevant stakeholders during this phase. Thereafter, the defined MVP has to be approved by the steering committee (refer to the first checkpoint in Fig.3). If it gets rejected, a new Lean Inception should be conducted, potentially focusing on a different problem. Referring to the suggestive timeline, the typical duration of a Lean Inception is of five business days [3]. However, in our specific case, we have managed to conduct them within three business days.

In the *Technical Feasibility* phase, the development team, assisted by the research team and the DevOps analyst, starts investigating the technical feasibility of implementing the features identified during the Lean Inception. Following the tracer bullet strategy [12], this phase typically serves as proof that the architecture is compatible and feasible and that there is a way to solve the problem with reasonable effectiveness, as well as providing a working, demo-able skeleton with some initial implementations.

The *Conception* involves the PO detailing the MVP features identified during the Lean Inception by applying product backlog building dynamics with the customer representatives, followed by other typical requirements elicitation techniques (e.g., interviews), to specify user stories. Additionally, aware of severe negative impacts of underspecified agile requirements [13], we complement user stories by specifying Behavior-Driven Development (BDD) scenarios that can later be used as objective acceptance criteria [14]. During the conception phase, the UX/UI team participates by creating low-fidelity prototypes (e.g., mock-ups) for requirements validation and high-fidelity UI prototypes for usability testing.

At the end of the conception, the agile requirements specification (containing user stories, BDD scenarios, and mock-ups) is reviewed and validated with the customer, and usability tests are conducted on the high-fidelity prototypes. It is noteworthy that careful requirements reviews (e.g., inspections) are among software engineering's best practices [15], capturing about 60% of the defects early, when they are cheaper to fix, significantly reducing rework, overall development effort, and delivery schedules [16]. Additionally, defects in requirements have other severe consequences, including customer dissatisfaction and overall project failure [17]. Thus, this phase, concerning the specification of what should be implemented, deserves special attention.

The second checkpoint involves the steering committee analyzing the requirements specification, together with the results of the technical feasibility assessment, requirements review, and usability tests, to decide whether the MVP should be developed.

Thereafter, the *Agile Development* phase involves the development team, with the support of the research team, implementing the MVP. The support of the research team is typically welcome for more complex specific parts (e.g., building machine learning models). Basically, this phase follows standard Scrum-based development with sprint planning, daily meetings, and sprint review cycles. For quality improvement purposes, we recommend using modern code reviews, which enable identifying faults, improving solutions, and sharing knowledge and code ownership [18]. While the sprint duration could be adjusted, in our specific case, we use sprints of two weeks and a custom dashboard that allows monitoring the overall team progress (*cf.* Section 5).

Once the MVP is developed, the next checkpoint involves the PO presenting the MVP to the steering committee, so that they can decide upon its transition into production. While this major checkpoint happens at the end of development, the customer representatives (BOs) are also involved in the sprint planning and sprint review activities during the development period, where they can always provide feedback to help co-creating the product that best fits their business needs.

Finally, the *Transition* phase involves the development and infrastructure team preparing the MVP for beta testing in its final environment and assessing the business hypotheses. The last checkpoint concerns analyzing continuous experimentation results, to investigate whether the business hypotheses were achieved and whether it is worth investing in another Lean R&D cycle to further improve the product (in this case the Lean Inception could be replaced by a simplified product increment planning ceremony). The research team is supposed to design the experiment plan, which should outline how to instrument the product to allow gathering the measurements required to test the business hypotheses, and eventually building other assessment instruments (e.g., questionnaires to measure user satisfaction). It is noteworthy that we intend to continuously improve the approach based on causal analysis process improvement practices [19].

4 Case Study Design

The description of our case study design is based on the guidelines for conducting case study research in software engineering by Runeson *et al.* [20].

4.1 Context

Petrobras is the largest company in Brazil and is active in the oil, natural gas, and energy industry. In 2019 they established a new board focusing on digital transformation and identified and prioritized several digital transformation opportunities within different business areas.

Aiming at coping with their digital transformation needs, CENPES partnered up with PUC-Rio's informatics department to establish the ExACTa initiative. Differently from previous experiences, this one should function with an open scope, following agile practices for Research and Development (R&D) to enable focused and fast deliveries of Minimal Viable Products (MVPs) that can be used to test digital transformation business hypotheses. Of course, such a cooperation term relies on strong customer involvement and a previously established relationship of trust between the two parties. The ExACTa initiative was launched in September 2019, and the first step involved designing Lean R&D.

The first two projects started in December 2019, and their first MVPs were delivered within a four-month timeframe. Currently, the ExACTa initiative runs four such projects in parallel. To cope with these demands, the initiative counts on four professors of the informatics department (active in the areas of data science, software engineering, optimization, and human-computer interaction), and hired 21 additional full-time employees (1 scrum master, 1 research team lead, 1 UX/UI team lead, 12 developers, 4 research team members, 1 UX/UI analyst, and 1 DevOps and infrastructure analyst). The case study concerns the first two projects. More details on the case and subject selection are provided in Section 4.3.

4.2 Goal and Research Questions

The goal of the case studies can be defined, following the GQM template [21], as follows: "*Analyze* the Lean R&D approach *with the purpose of* characterization *with respect to* its overall outcomes and stakeholder perceptions, and the acceptance of its main building blocks *from the point of view of the* stakeholders and researchers *in the context of* the projects undertaken within the ExACTa co-creation initiative." From this goal, we derived the research questions.

RQ1: What have been the overall outcomes of the Lean R&D approach? To answer this question, we access the data from the agile management system (Microsoft DevOps) and discuss deliverables that have been accepted by the customer.

RQ2: What are the perceptions of the main stakeholders on the Lean R&D approach so far? To answer this question, we asked the main Lean R&D stakeholders from the involved business areas for feedback and analyzed this feedback qualitatively.

RQ3: What is the acceptance of applying Lean R&D's Lean Inceptions to define MVPs? To answer this question, we applied a survey based on the *Technology Acceptance Model (TAM)* [22], which has been commonly used to measure acceptance [23], to all Lean Inception participants.

RQ4: Does Lean R&D's early technical feasibility assessment phase help to address research-related uncertainties? To answer this question, we analyze the tasks and comments within the agile management system and the meeting minutes, to retroactively reflect on each case.

RQ5: Does Lean R&D's agile scrum-based and research-supported development fit well into the digital transformation initiative? To answer this question, we reflect on the dynamics of scrum plannings, reviews, and daily meetings, and data from the agile management system.

RQ6: Does continuous experimentation help to test business hypotheses and provide feedback? To answer this question, we reflect on data regarding the usage of the solutions and on additional evaluation instruments (questionnaire) used to assess the MVP's business hypotheses.

4.3 Case and Subject Selection

We selected the first two projects by convenience. Details on each case follow.

Case 1: Intelligent monitoring of gas emissions by oil refineries. This case addresses a need of the industrial business area within Petrobras, and concerns building artificial intelligence models to predict refinery gas emissions, based on operation controls and environmental sensor data. This system should help to improve the capability of environmental monitoring and help to reduce environmental complaints by the community (e.g., regarding bad smells). Besides the ExACTa team, this case had three employees of Petrobras (BOs) working co-located within the ExACTa initiative space at PUC-Rio[1]. All these team members participated in the Lean Inception, as well as the sponsor at CENPES, the sponsor at Petrobras' industrial area, and representatives of employees of the target refineries.

Case 2: Intelligent logistics control of service providing ships, helping to identify and handle off-hire situations. This case addresses a need of the Logistics business area within Petrobras, and concerns building intelligent controls, integrating information from several systems to identify and handle off-hire situations (i.e., situations in which a chartered ship is not available), which should be deducted from payments to the service providers (as well as the fuel used during off-hire periods). Besides the ExACTa team, this case had four employees of Petrobras (BOs) directly involved in co-creating the solutions. While they did not work full time, they participated in all Scrum plannings and reviews and were always available remotely and willing to contribute. All these team members participated in the Lean Inception, as well as the sponsor at CENPES, the sponsor at Petrobras' logistics area, and employees involved in operating ships and administering ship charter contracts.

4.4 Data Collection and Analysis Procedures

The author team includes members of both cases (they participated in discussions regarding the approach and helped to adjust it until reaching the herein described format) and has direct access to all other team members at PUC-Rio and Petrobras. The authors also had representatives in both Lean Inceptions, in the sprint plannings, reviews, and daily meetings, allowing them to precisely observe the approach in its real context. Moreover, they had complete access to the agile management system (Microsoft DevOps) and all project-related artifacts, including meeting minutes.

Additionally, as the Lean Inceptions involved several stakeholders, we conducted a survey based on the TAM questionnaire and open questions, which were analyzed qualitatively and anonymously. Also, for continuous experimentation purposes, we measured usage data of the provided solutions and applied additional questionnaires. Moreover, we asked the sponsors at Petrobras' involved business areas for additional feedback on their perceptions. This feedback was also qualitatively analyzed to help us further understand the overall acceptance from a managerial perspective.

4.5 Validity Procedures

All the quantitative data was collected from the agile management system and real project artifacts. The agile management system is directly integrated with changes in

---

[1] Since March 23rd activities moved to home-office due to COVID-19. Following the recommendations in [24] as much as possible and using proper remote tool support (Microsoft Azure DevOps and Teams) allowed us to keep the Lean R&D approach running remotely.

the source code and any other project artifact. The status of tasks within this system is verified on a daily basis during the daily meetings. Anonymity was employed in all questionnaires, allowing stakeholders to freely express their opinions.

5 Results and Discussion

Hereafter we describe the results of the case studies. We decided to describe them together in a joint analysis and discussion, focusing on answering each research question based on observations from both cases.

RQ1: What have been the overall outcomes of the Lean R&D approach? Regarding the outcomes, both cases recently had their first MVP accepted by the customer and delivered to the end-user within a four-month timeframe. *Case 1* delivered an MVP with 6 features (detailed in 28 user stories), while *Case 2* delivered an MVP with 5 features (detailed in 53 user stories). Fig. 4 shows screenshots of functionalities developed for *Case 1* and *Case 2*. MVPs are now available to the end-users for beta testing, evaluating the associated business hypotheses and identifying opportunities for further improvement (e.g., in the format of new MVP versions). The MVP for *Case 1* uses a decision tree model to predict the probability of gas emissions above a certain level and potential causes and enables to register and correlate complaints from the community. The MVP for *Case 2* uses intelligent data crossings to enable effectively detecting and handling off-hire events within ship charter contracts.

Regarding the process outcomes, based on data from the agile management system, it is observable that the development team adjusted to the process and produced the Lean R&D artifacts (process outcomes) as expected. All Lean Inception artifacts were organized in the agile management system's wiki. During the conception phase, features identified in the Lean Inceptions were detailed into user stories with BDD scenarios, mock-ups were built and high-fidelity prototypes designed and validated.

(a) (b)

Fig. 4. Screens of developed functionalities for *Case 1* (a) and *Case 2* (b). Both had their first MVPs delivered within a four-month timeframe. Figures included for illustrative purposes, the focus of this paper is on the approach, not on the implemented solutions.

With respect to the technical feasibility and research and development artifacts, in *Case 1*, due to access to confidential data, the team had to use an external Petrobras repository for committing their artifacts (e.g., code, models, and configuration files). Therefore, commits were not directly linked to the tasks in the management system. In *Case 2*, the agile management system's integrated Git repository was used, creating a branch for each task and using modern code reviews to assure code quality during pull-requests.

Regarding the sprint plannings and reviews, meeting minutes were registered for each event (every two weeks) in the agile management system. For *Case 1,* we also conducted weekly managerial status report meetings and registered meeting minutes for them, as critical stakeholders could not promptly adjust their activities to attend our sprint planning and review schedules.

RQ2: What are the perceptions of the main stakeholders on the Lean R&D approach so far? We asked the main stakeholders at Petrobras' industrial (*Case 1*) and logistics (*Case 2*) areas for feedback and analyzed this feedback qualitatively. Therefore, we reached out to them, asking them to write a short open text on their overall perceptions so far. The feedback was extremely positive.

The manager responsible for the industrial business area emphasized the co-creation process, effectiveness in adding business value, speed, and the evolutionary MVP approach: "The integration of the technical process engineering and IT teams of Petrobras with the development teams at PUC-Rio is a main advantage for achieving effective results, adding business value in a fast, collaborative and evolutionary way." It is noteworthy that this area had three Petrobras employees working most of the time collocated (after the pandemic virtually) with the team, offering tremendous help towards achieving the goals and co-creating the solutions.

The representative of the logistics area was in-line with these arguments and emphasized co-creation, agility, and efficiency: "The co-creation partnership with ExACTa has reflected the goals pursued by the logistics area: alignment between planning and accomplishments, agility and efficiency." He also wrote that "The initial impact of the different working method proposal, given the results, soon gave way to confidence. The team demonstrates control over the development, with continuous communication and predictability over the terms and scope of agreed deliveries". This statement highlights the adaptation and acceptance of the new agile method, after a completely understandable initial skepticism, observed from stakeholders of both cases, at the beginning.

RQ3: What is the acceptance of applying Lean R&D's Lean Inceptions to define MVPs? The Lean Inceptions were conducted involving the identified key stakeholders for each case. Fig. 5 shows part of both Lean Inception teams in action. It illustrates the dynamics of co-creating a joint vision of an MVP that should add business value, be technically feasible, and user-friendly (Lean Inception includes a specific business, technical, and UX review activity before sequencing identified features into MVPs).

(a)

(b)

Fig. 5. Kicking off the Lean Inception of *Case 1* (a) and discussing the final feature sequencing with some Lean Inception participants of *Case 2* (b).

To investigate the acceptance, we applied a questionnaire, designed based on the TAM questionnaire [22] adding an open text question asking for suggestions. The questionnaire was applied to all Lean Inception participants, but answering was not mandatory (eleven participants answered in both cases). An excerpt from the results of the TAM questionnaire, regarding the stakeholder perceptions that best help answering RQ3 (speed and precision when defining the MVP, usefulness, ease of use, and intention to adopt) is shown in Table 1 for *Case 1* and Table 2 for *Case 2*. While participants were asked to identify whether they were from Petrobras or PUC, answers were anonymously collected.

To facilitate an overview of the results, we highlighted the cells with the highest value within each line. Based on these highlights, it is possible to observe an overall acceptance of using Lean Inceptions to define the joined vision of the MVP, with mainly neutral to positive perceptions in *Case 1* and mainly positive perceptions in *Case 2*. It may be possible to explain the differences between the cases based on the fact that the Lean Inception conducted in *Case 1* was the overall first one conducted within the ExACTa initiative. Also, based on the feedback collected from the open questions in *Case 1*, we held a contextualization meeting at the customer side before starting the inception of *Case 2*. We also identified some improvement suggestions regarding details of the Lean Inception method within the provided answers.

Table 1. Lean Inception TAM Questionnaire for *Case 1*.

Statement	***Comp.***	***#Answers***	***SD***	***D***	***N***	***A***	***SA***
High Speed	Petro.	5	0%	0%	20%	80%	0%
	PUC	6	0%	17%	17%	33%	33%
High Precision	Petro	5	0%	0%	80%	20%	0%
	PUC	6	0%	0%	50%	50%	0%
High Usefulness	Petro	5	0%	0%	40%	40%	20%
	PUC	6	0%	0%	17%	33%	50%
Easy to use	Petro.	4	0%	0%	75%	0%	25%
	PUC	6	0%	17%	33%	33%	17%
Intention to adopt	Petro	5	0%	0%	40%	40%	20%
	PUC	6	0%	17%	17%	33%	33%

SD: Strongly Disagree, D: Disagree, N: Neutral, A: Agree, SA: Strongly Agree.

Table 2. Lean Inception TAM Questionnaire for *Case 2*.

Statement	***Comp.***	***#Answers***	***SD***	***D***	***N***	***A***	***SA***
High Speed	Petro.	4	0%	0%	0%	75%	25%
	PUC	7	0%	14%	0%	29%	57%
High Precision	Petro	4	0%	0%	25%	75%	0%
	PUC	7	0%	0%	29%	29%	43%
High Usefulness	Petro	4	0%	0%	25%	50%	25%
	PUC	7	0%	0%	0%	43%	57%
Easy to use	Petro.	4	0%	0%	0%	75%	25%
	PUC	7	0%	0%	14%	57%	29%
Intention to adopt	Petro	4	0%	0%	0%	50%	50%
	PUC	7	0%	0%	0%	14%	86%

SD: Strongly Disagree, D: Disagree, N: Neutral, A: Agree, SA: Strongly Agree.

Based on these results and our overall perception, we believe that the Lean Inceptions helped to understand the overall context, enabling to outline an MVP and a prioritized set of features, which subsidize the next Lean R&D activities (e.g., the conception where features are detailed into user stories and the technical feasibilities, where the *tracerbullet* strategy is applied to check if it is possible to implement the identified features). Moreover, it also helped to understand the continuous experimentation needs, by identifying the business hypotheses. Among the open text answers the main opportunities for adjustment to the R&D context concern improving the business, technical, and UX review step, as some participants highlighted that this step should not be conducted with the entire group, but properly separating main stakeholders into specific groups for a more precise assessment. I.e., it was observed that developers are typically not able to appropriately judge the business value of features, while business stakeholders have similar difficulties with the technical review on feasibility and effort. Moreover, UX related stakeholders typically found the information gathered during the Lean Inceptions insufficient for subsidizing UX feature assessments. Indeed, in our experiences, the assessments had to be reviewed after the product backlog dynamics conducted during the conception phase.

RQ4: Does Lean R&D's early technical feasibility assessment phase help to address research-related uncertainties? We analyzed the tasks and comments within the agile management system, meeting minutes, and the observed experience within the projects. Analyzing the tasks indicated that in both cases, this phase was needed before starting the development sprints, enabling to address research-related uncertainties and infrastructural issues, also with the support from Petrobras' IT teams, as soon as possible.

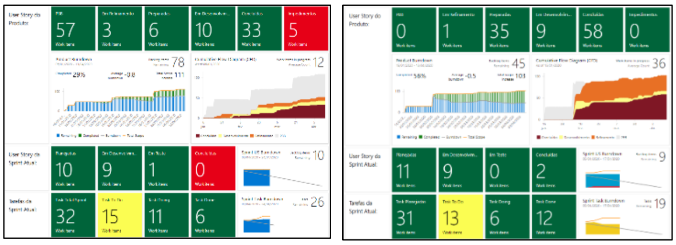
For *Case 1*, the tasks accomplished within this phase mainly concerned: (a) investigating alternatives for building a prediction model with reasonable accuracy, (b) testing integrations and access to required data, and (c) solving infrastructure-related problems. For *Case 2*, the tasks accomplished within this phase mainly concerned experimenting some architectural solution options and aligning them with Petrobras' standards and investigating the integration and compatibility with Petrobras' legacy systems.

At this point, it is important to highlight the support from the parallel research team and the infrastructure analyst. Of course, this support is also important during development, but in this early technical feasibility assessment phase, it is enabling and crucial. After the delivery of the MVP of *Case 1*, one of the developers mentioned within the team communication channel that "it would not have been possible to properly address this problem within the expected timeframe without the early investigations and support of the research team."

RQ5: Does Lean R&Ds agile scrum-based and research-supported development fit well into the digital transformation initiative? Here we reflect on the dynamics of scrum plannings, reviews, and daily meetings and the transparency provided by the agile management system. Our overall conclusion is that yes, it fits well when using Lean R&D adaptations (e.g., a strong focus on precise, agile specifications, addressing architecture and research uncertainties at the very beginning, and proving continuous research support to the development team).

Sprint planning, review, and daily meetings played a key role in facilitating management and communication and establishing a co-creation team spirit. Transparent and continuous access to all sprint planning and review meeting minutes by all stakeholders helped to provide transparency and building trust. Transparency was also provided by properly configuring tool support for monitoring development progress. We designed a customized dashboard, used within all projects, to show the overall project progress in real-time (i.e., as soon as a developer concludes a task, the dashboard is automatically updated). The dashboards of *Case 1* and *Case 2* can be seen in Fig. 6. We keep these dashboards projected and continuously visible to the whole project team (also always remotely accessible through the Microsoft Azure DevOps system). Nevertheless, considering the initiative as a whole, even organizing information on the different projects with similar dashboards, we noticed shortcomings for managing information at a portfolio level of abstraction.

Initially, we faced some resistance from customers of both cases in following the agile co-working philosophy. As the results started to be delivered, this resistance was replaced by confidence, and a joyful co-creation environment was established. We believe that complete progress transparency also helped in this direction.



(a) (b)

Fig. 6. Standardized and interactive project monitoring dashboards for *Case 1* (a) and *Case 2* (b), showing the progress of the product, the current sprint, and of minor tasks.

RQ6: Does continuous experimentation help to test business hypotheses and provide feedback? The Lean Inceptions helped to identify target business hypotheses for continuous experimentation. We will focus the discussion of this research question on MVP of *Case 1*, mainly due to space constraints and because this one started being used by the end-users earlier (at the beginning of June, while MVP of *Case 2* started being used at the beginning of July). The information we have so far for *Case 2,* is that, according to the representative of the logistics area, "employees involved in operating ships and administrating ship charter contracts [i.e., end users] are satisfied with the delivered MVP and were able to start using it after a very short training period." Indeed, after some days of initial usage, they identified and started handling 16 off-hire events through the system. Nevertheless, this information does not allow us to test the business hypotheses yet (which involve comparing off-hire deductions and handling time).

MVP of *Case 1* was deployed in the cloud, and we could collect usage data directly from the Microsoft Azure cloud platform. We measured the distribution of usage time (proxied by the amount of exchanged data) and the number of users (proxied by the number of active sessions) over time. Fig. 7 shows these measures for the period of June 10th to July 10th. It is possible to observe an increase in the usage time and also in the number of users (active sessions). Two refinery operators at Petrobras started using the solution for monitoring gas emissions at least once a week (eventually, there were more than two simultaneous users). It is possible to see that they started spending more time in the system as they were becoming more familiar with it, which provides a preliminary indication of its perceived usefulness.

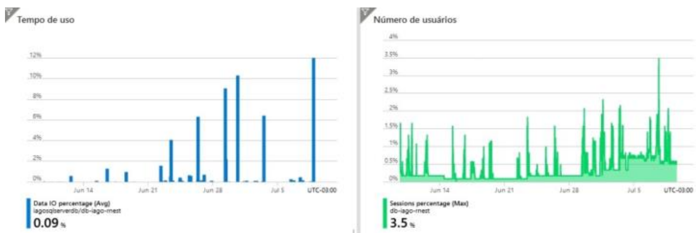


Fig. 7. Microsoft Azure metrics used as proxies for usage time and number of users.

Regarding the evaluation of the business hypotheses, there were two business hypotheses for *Case 1*. *Hypothesis 1*: "We believe that the *MVP for Case 1* will be able to *reduce the number of complaints by the society regarding bad smells related to refinery gas emissions*, we will know that this happened based on *the average number of complaints*"; and *Hypothesis 2*: "We believe that the *MVP for Case 1* will be able to *allow faster diagnosis of the causes*, we will know that this happened based on *the average time spent on the diagnosis*." In the case of the diagnosis, it was supported by showing the decision tree path that led to the inference of high gas emission, and also letting users consult the whole decision tree.

Unfortunately, while we provided means to monitor the related metrics, the time of deployment would not be sufficient to observe changes in the averages yet. Therefore, we used an additional instrument to preliminarily assess our hypotheses; a questionnaire answered directly by the end-users in the refinery. Both main users answered that they completely agreed that the solution would help to lower the number of complaints and also the cause identification time. Moreover, they provided valuable feedback, with new features to be included in the next product increment (e.g., automatic notification alerts) and also showing to be satisfied with the provided solution. E.g., one of them mentioned that "the interface is well organized and information is properly presented, allowing interactions to filter the period and to understand the decision tree inferences."

6 Concluding Remarks

In this paper, we presented the Lean R&D approach, tailored to meet digital transformation related needs, including the ability to fail fast and agile and fast-paced deliveries of complex solutions. The development of such products commonly involves R&D efforts. However, we found no digital transformation focused approach available that appropriately considers integrating R&D efforts into an agile development philosophy. Lean R&D was designed with this focus, based on the following building blocks: (i) Lean Inceptions, to allow stakeholders to jointly outline a Minimal Viable Product (MVP); (ii) parallel technical feasibility assessment and conception phases; (iii) scrum-based research and development management; and (iv) strategically aligned continuous experimentation to test business hypotheses.

We applied Lean R&D in two case studies. Lean R&D enabled defining a joined MVP vision, addressing research-related uncertainties early, and to efficiently deliver valuable MVPs which were accepted by the end-users. Based on our experience, precisely defining business hypotheses and the focus on continuous experimentation strengthen the *BizDev* integration, helping to guide the overall development efforts since the beginning and avoiding to lose the focus on the main business goals. This business strategy alignment, the defined roles and co-creation philosophy with strong integration between Petrobras and PUC-Rio's teams, and the continuous support of a highly qualified research team, exploring synergies with the university's research program, were observed as key success factors. Main opportunities for improvement, based on our lessons learned, rely on better adapting Lean Inceptions to the DT context and on scaling the approach to a project portfolio level of abstraction.

While we are aware that these case studies were conducted in a specific context, we believe that sharing the approach and our evaluation experiences could help other organizations involved in digital transformation initiatives.

Acknowledgments

The authors would like to thank all ExACTa PUC-Rio and Petrobras employees involved in the projects for their trust and dedication to the new initiative.

References

1. Matt, C., Hess, T., Benlian, A.: Digital transformation strategies. Business & Information Systems Engineering 57(5), 339–343 (2015).
2. Fitzgerald, B., Stol, K.J.: Continuous software engineering: A roadmap and agenda. Journal of Systems and Software 123, 176–189 (2017).
3. Caroli, P.: Lean Inception: how to align people and build the right product. Editora Caroli (2018).
4. Fagerholm, F., Guinea, A.S., Mäenpää, H., Münch, J.: The RIGHT model for continuous experimentation. Journal of Systems and Software 123, 292–305 (2017).
5. Kalinowski, M., Batista, S.T., Lopes, H. *et al.*: Towards lean R&D: an agile research and development approach for digital transformation. In: Euromicro Conference on Software Engineering and Advanced Applications (SEAA), 5p. (*in press*), Portoroz, Slovenia (2020).
6. Reinertsen, D., Shaeffer, L.: Making R&d lean. Research-Technology Management, 48(4), 51-57 (2015).
7. Ries, E.: The Lean Startup: how today's entrepreneurs use continuous innovation to create radically successful businesses. Crown Business, New York (2011).
8. Debois, P.: Devops: a software revolution in the making. Journal of Information Technology Management 24(8), 3–39 (2011).
9. Bosch, J.: Building products as innovation experiment systems. In: Cusumano M.A., Iyer B., Venkatraman N. (eds.) International Conference on Software Business (ICSOB), LNBIP vol. 114, pp. 27–39. Springer (2012).
10. Ohno, T.: Toyota Production System: Beyond Large-Scale Production. CRC Press (1988).
11. Wagner, S., Mendez, D., Felderer, M. *et al.*: Status quo in requirements engineering: A theory and a global family of surveys. ACM Transactions on Software Engineering and Methodology (TOSEM), 28(2), 1-48 (2019).
12. Thomas, D., Hunt, A.: The Pragmatic Programmer: your journey to mastery. 2nd edn. Addison-Wesley Professional (2019).
13. Mendes, T.S., de Freitas Farias, M.A., Mendonça *et al.*: Impacts of agile requirements documentation debt on software projects: a retrospective study. In: Proceedings of the ACM Symposium on Applied Computing (SAC), pp. 1290–1295. Pisa, Italy (2016).
14. Smart, J.F.: BDD in Action: Behavior-driven development for the whole software lifecycle. Manning (2015).
15. Aurum, A., Petersson, H., Wohlin, C.: State-of-the-art: software inspections after 25 years. Software Testing, Verification and Reliability 12(3), 133–154 (2002).
16. Boehm, B., Basili, V.R.: Software defect reduction top 10 list. IEEE Computer 34(1), 135–137 (2001).
17. Mendez, D., Wagner, S., Kalinowski, M. et al.: Naming the Pain in Requirements Engineering – Contemporary problems, causes, and effects in practice. Empirical Software Engineering 22 (5), 2298–2338 (2017).
18. Bacchelli, A., Bird, C.: Expectations, outcomes, and challenges of modern code review. In: International Conference on Software Engineering, pp. 712–721. San Francisco, USA (2013).
19. Kalinowski, M., Mendes, E., Card, D. N., Travassos, G. H.: Applying DPPI: A defect causal analysis approach using bayesian networks. In: International Conference on Product Focused Software Process Improvement (PROFES), pp. 92-106. Oulu, Finland (2010).
20. Runeson, P., Host, M. Rainer, A., Regnell, B.: Case study research in software engineering: Guidelines and examples. J. Wiley (2012).
21. Basili, V.R., Rombach, H.D.: The TAME project: Towards improvement-oriented software environments. IEEE Transactions on software engineering 14(6), 758–773 (1998).
22. Davis, F.D.: Perceived usefulness, perceived ease of use, and user acceptance of information technology. MIS Quarterly 13(3), 319–340 (1989).
23. Turner, M., Kitchenham, B., Brereton, P., Charters, S., Budgen, D.: Does the technology acceptance model predict actual use? A systematic literature review. Information and Software Technology 52 (5), 463–479 (2010).
24. Ralph, P., Baltes, S., Adisaputri, G. *et al.*: Pandemic programming: How COVID-19 affects software developers and how their organizations can help. Empirical Software Engineering, accepted for publication, 34p., in press (2020).