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

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***Abstract*— [Context] Petrobras is Brazil's largest publicly-held company, operating in the oil, natural gas, and energy industry. Internal efforts enabled Petrobras to identify Digital Transformation (DT) opportunities to further promote their operational excellence. While addressing these opportunities typically requires Research and Development (R&D) uncertainties that could lead traditional R&D cooperation terms to be negotiated in years, there are time-to-market constraints for fast-paced deliveries to experiment solution options. Having this in mind, they partnered up with PUC-Rio to establish a new DT initiative. [Goal] The goal of this paper is to present the Lean R&D approach, tailored within the new initiative to meet the aforementioned DT needs. [Method] 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) 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. We report on first experiences of applying Lean R&D in practice. [Results] Lean R&D enabled addressing research-related uncertainties early and to efficiently deliver valuable MVPs within fast-paced four months cycles. [Conclusions] In our first experiences Lean R&D showed itself suitable for supporting DT initiatives. However, more formal case studies are needed. The business strategy alignment and the continuous support of a highly qualified research team were considered key success factors.**

Keywords*— *digital transformation, agile methods, lean, research and development, continuous experimentation.

I. Introduction

Digital Transformation (DT) typically involves the use of new and frequently changing digital technology to solve business problems. The resolution of such problems frequently involves transformations of key business operations that may affect organizational structures, processes, and products. Organisations of almost all industries are conducting DT initiatives to explore digital technologies and their benefits [1].

Petrobras is a large Brazilian company active in the oil, natural gas, and energy industry. Internal efforts within their main business areas enabled them to identify DT opportunities that could help to leverage their operational excellence. Such DT opportunities typically involve Research and Development (R&D). CENPES is the research centre of Petrobras, responsible for coordinating and conducting research initiatives, which commonly involve cooperation terms with research institutes. These terms were usually designed in a plan-driven manner, with deliveries taking up to years. However, in DT contexts, there are time-to-market constraints and a need for fast-paced deliveries to experiment solution options.

To address these DT idiosyncrasies, they partnered up with PUC-Rio to establish a new initiative, called ExACTa (Experimentation-based Agile Co-creation initiative for digital Transformation). 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 DT business hypotheses. ExACTa was launched in September 2019 and the first step involved designing an R&D approach that would allow such fast MVP deliveries, called Lean R&D.

Lean R&D 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); (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. Moreover, the initiative counts on a dedicated research team, specialized on data science and machine learning, to support the development team with parallel investigation activities.

The goal of this paper is to present Lean R&D, and to report on our first experiences with the approach. These experiences concern applying Lean R&D in practice to build DT 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. Throughout these experiences, Lean R&D showed itself suitable for supporting DT initiatives. The *BizDev* business process integration strategy and the continuous support of a qualified research team were observed as key success factors.

II. Background

The following two subsections provide background on continuous software engineering [2] and Lean Inceptions [3]. We used the dynamics of the first one to narrow the gap between the business strategy and experimenting solution options. Lean Inceptions were used to help aligning stakeholders to outline DT enabling MVPs.

A. Continuous Software Engineering

Fitzgerald and Stol [2], in their paper providing a roadmap and research agenda for continuous software engineering, argue

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that business, development, and operations should continuously be aligned with each other. Fig.1 provides an adapted and simplified representation of such alignment. 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. Finally, continuous experimentation focuses on conducting experiments with stakeholders consisting of repeated Build-Measure-Learn cycles [4][5].

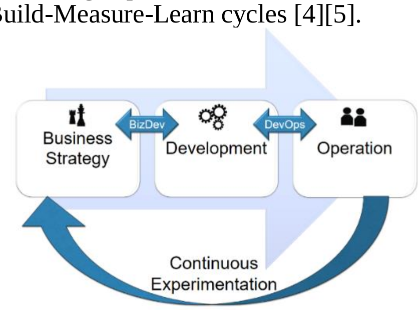

Fig. 1. Relations between business strategy, development, and operation. Adapted from [2].

Reflecting on the implications of these alignments in the context of engineering DT enabling software products, *BizDev* and continuous experimentation play a key role. DT commonly involves changes in key business operations that affect business processes and 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 DT contexts is also highlighted by Fagerholm *et al.* [5].

B. *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 [3].

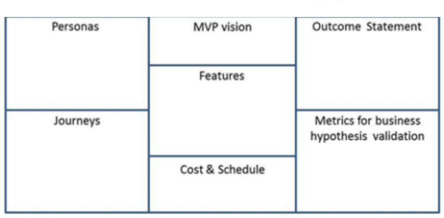

Fig. 2. Lean Inception MVP canvas. Adapted from [3].

III. The Lean R&D Approach

Our goal was to design an R&D approach for DT, based on agile and continuous software engineering principles. We 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 removed [6]. To achieve this goal, there should be a focus on the business strategy and on its alignment with development (*BizDev*) [2].
- *R2: Allow to 'fail fast'.* This involves employing the Lean Startup 'fail fast' concept [7], which enables handling opportunities and risks involved in experimenting DT solution options.
- *R3: Enable addressing complex problems.* DT commonly involves applying cutting-edge technology to solve problems in domains in which they were never applied before. Therefore, domain experts from the customer side and a qualified research team should be involved.

A. *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 *BizDev* and continuous experimentation. An overview of the designed approach is shown in Fig. 3. It is possible to observe four checkpoints and support of a dedicated research team to technical solution related activities. Hereafter we briefly describe the involved roles and activities.

1) Roles. The following roles are involved in the approach:

- *Steering Committee.* The main role of the steering committee is to assess the projects at the depicted checkpoints: (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 DT challenges.
- *Project Manager (Scrum Master).* Facilitates the Lean Inceptions and manages the agile research and development teams, assuring that the overall approach is being appropriately followed. We recommend at least one manager for each set of four projects.
- *Product Owners (POs) and customer representatives.* As in traditional Scrum, POs are responsible for maximizing the business value of the product resulting from the work of the development team. We recommend at least one PO for each set of two projects, and strong assistance of customer representatives (at least one per project).
- *Developers*. The development teams. Typically, there should be three to five developers dedicated to each project.
- *Research team*. The role of the research team is to support the development teams in an early technical feasibility assessment and in complex tasks during development (e.g., investigating machine learning techniques to be used). We recommend one research lead for each set of 4 projects and one researcher dedicated to each project.
- *UX/UI design team*. Responsible for designing user interaction mock-ups and high-fidelity prototypes to subsidize development. We recommend at least one UX/UI team lead and one UX/UI analyst serving each set of four projects.
- *DevOps and infrastructure analyst*. Responsible for providing the DevOps infrastructure. We recommend at least one DevOps analyst for each set of four projects.

2) Activities. Hereafter we describe the flow of activities included in the Lean R&D approach.

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 (*cf.* 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, it is noteworthy that 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. If the idea of the MVP gets approved, two phases start in parallel: *Technical Feasibility* and *Conception*.

During *Technical Feasibility*, the development and research teams, assisted by the infrastructure analyst, investigate the technical feasibility of implementing the features identified during the Lean Inception. This phase typically serves as a 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 containing 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 in order to specify user stories. Aware of severe negative impacts of underspecified agile requirements [8][9], we complement user stories by specifying Behavior-Driven Development (BDD) scenarios that can later be used as objective acceptance criteria [10]. Moreover, the UX/UI team participates in creating low-fidelity prototypes (e.g., mock-ups) for requirements validation and high-fidelity UI prototypes for usability testing. These activities help to improve the specifications and to avoid technical usability debt [11] since the beginning.

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, capturing about 60% of the problems early, when they are cheaper to fix, significantly reducing rework, overall development effort, and delivery schedules [12]. Moreover, problems in requirements specifications have other severe consequences, including customer dissatisfaction and overall project failure [13]. Hence, this phase should deserve special attention, as in software engineering in general.

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

Thereafter, the *Agile Development* phase involves the developers, 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). This phase follows standard Scrum based development with sprint planning, daily meetings and sprint review cycles.

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. It is important to state that customer representatives are also involved in the sprint planning and review activities during development, where they can always provide feedback to help co-creating the product that best fits their business needs.

Finally, the *Transition* phase involves: (i) the development and infrastructure team preparing the MVP for beta testing in its final environment; (ii) the co-creation team aligning the use of the product by defining the new business process and user workflows; and (iii) assessing the business hypotheses. The research team is supposed to design the experiment plan, instrumenting the product to allow appropriate monitoring and building other assessment instruments (e.g., questionnaires) to test the business hypotheses. The last checkpoint concerns analysing continuous experimentation results, to investigate if the business hypotheses were achieved and whether to undertake another Lean R&D cycle.

This overall description represents the initial conception of the Lean R&D approach. We intend to continuously improve the approach based on evidence-based investigations and causal analysis practices [14].

IV. First Experiences of Applying Lean R&D

The first two projects, out of four currently in progress, started in December 2019 and their first MVPs were delivered within a four-month timeframe. To cope with the four projects demand, the ExACTa team counted 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

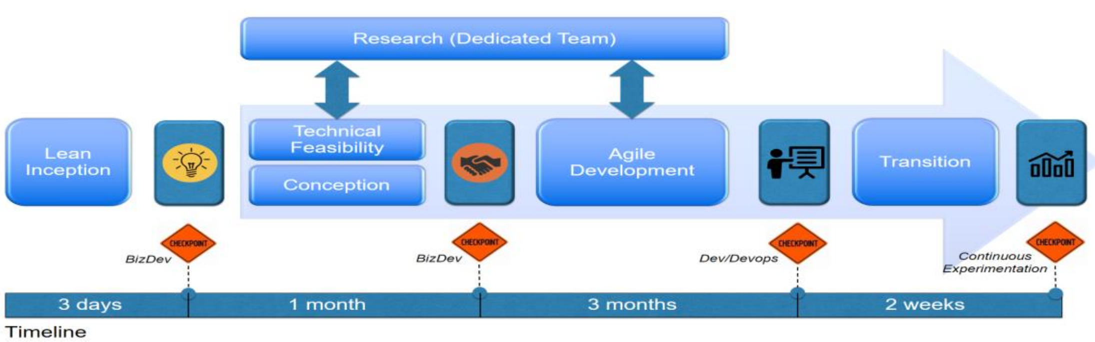

Fig. 3. Lean R&D approach. The timeline is illustrative and specific to our instantiation.

developers, 4 research team members, 1 UX/UI analyst, and 1 devops and infrastructure analyst). The initial experiences herein reported concern the first two projects.

Project 1: Intelligent monitoring of gas emissions by oil refineries. This project 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. These models should help to improve environmental monitoring in order to reduce environmental impacts. This project had three employees of Petrobras (customer PO representatives) working co-located with the ExACTa initiative employees at PUC-Rio.

Project 2: Intelligent logistics control of service providing ships, helping to identify 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 potential off-hire situations (i.e., situations in which a chartered ship is not available), which should lead to service provider payment deductions. Besides the ExACTa team, this project had four employees of Petrobras (customer PO representatives) directly involved in co-creating the solutions. While they did not work full time at ExACTa, they participated in all Scrum planning and review activities and were always available remotely and willing to contribute.

Based on our initial experiences, we provide the insights on Lean R&D, concerning: (i) the overall approach outcomes; (ii) perceptions by the main stakeholders; (iii) acceptance of applying Lean Inceptions; (iv) the early technical feasibility assessment; (v) agile scrum-based and research supported development; and (vi) *Bizdev* and continuous experimentation.

Overall approach outcomes. 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. *Project 1* delivered an MVP with 6 features (detailed in 28 user stories), while *Project 2* delivered an MVP with 5 features (detailed in 53 user stories). 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 increments). The first MVP for *Project 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 first MVP for *Project 2* uses intelligent data crossings to enable effectively detecting and handling off-hire events within ship charter contracts.

Based on data from the agile management system (we used Microsoft Azure DevOps), it was possible to observe that the team followed the approach and produced all Lean R&D artefacts as expected. Lean Inception artefacts 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 were designed and validated. With respect to technical feasibility and research and development artefacts, in *Project 1*, due to the use of confidential data, the team had to use an external Petrobras repository for committing their artefacts (e.g., code, models, and configuration files). Therefore, commits were not directly linked to the tasks in the management system. In *Project 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. Finally, regarding the sprint plannings and reviews, meeting minutes were registered for each event in the agile management system.

Main stakeholder perceptions. We asked the main stakeholders of Petrobras' industrial (*Project 1*) and logistics (*Project 2*) areas for feedback and analyzed this feedback qualitatively. Therefore, we reached out to them, asking them to write a short open text with one or two phrases on their overall perceptions so far.

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 research and development teams at PUC-Rio is a main advantage for achieving effective results, adding business value in a fast, collaborative and evolutionary way". 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 to the new approach and its acceptance, after a completely understandable initial scepticism, observed in both projects at the beginning.

Acceptance of applying Lean Inceptions. The Lean Inceptions were conducted involving the identified key stakeholders for each project. We followed the Lean Inception dynamics for 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). To investigate the acceptance, we applied a questionnaire, designed based on the TAM questionnaire [15]. The questionnaire was applied to all Lean Inception participants, but answering was not mandatory and answers were anonymously collected.

Based on the results concerning perceptions on the speed and precision when defining the MVP, usefulness, ease of use, and intention to adopt, it was possible to observe an overall acceptance of using Lean Inceptions to define the joined vision of the MVP, with mainly positive perceptions in Project 1 and positive to strongly positive perceptions in Project 2. Detailed results of the TAM questionnaire results were suppressed due to space constraints. However, based on the results and our perceptions, 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. Moreover, it also helped to understand the continuous experimentation needs, by allowing to identify business hypotheses.

Early technical feasibility assessment. We analyzed the tasks and comments within the agile management system, meeting minutes, and the observed experience within the projects to assess the value of the early technical feasibility assessment phase. Analyzing the tasks indicated that in both projects this phase enabled addressing research-related uncertainties and infrastructural issues as soon as possible. For *Project 1*, the tasks accomplished within this phase mainly concerned: investigating alternatives for building a prediction model with reasonable accuracy, testing integrations and access to required data, and solving infrastructure related problems. For *Project 2*, the tasks accomplished within this phase mainly concerned experimenting some architectural solution options 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 was perceived as enabling and crucial.

Agile scrum-based and research supported development. Our overall perception is that, considering our 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), scrum fits will into Lean R&D,

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 sprint planning and review meeting minutes by all stakeholders helped to provide transparency and establishing trust. Transparency was also provided by properly configuring tool support for monitoring the 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). We keep these dashboards projected and continuously visible to the whole project team. Initially we faced some resistance from customers of both projects in following the agile co-working philosophy. As soon as the results started to be delivered this resistance was replaced by confidence and a joyful co-creation environment was established. We believe that the complete progress transparency helped in this direction.

***Bizdev* and continuous experimentation.** The Lean Inceptions helped to identify *BizDev* business hypotheses and to contextualize the need for adapting business processes. Continuous experimentation ought to be used to close the *BizDev* feedback cycle. Unfortunately, given that the MVPs were just delivered, we were not able to collect experiment data from actual use at the time of this submission.

V. Concluding Remarks

In this paper we presented the initial version of our Lean R&D approach, tailored to meet digital transformation related product development needs, including the ability to fail fast and agile and fast-paced deliveries. The development of such products commonly involves a mixture of R&D efforts. However, we found no digital transformation focused approach available that appropriately considers combining R&D efforts and integrating them 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 also report on our first experiences applying Lean R&D. We are aware that more detailed case studies should be conducted and reported. During the experiences Lean R&D enabled defining a joined MVP vision, addressing research-related uncertainties early; and to efficiently deliver valuable MVPs within a four-month timeframe in both projects. The business strategy alignment and the highly qualified research and development teams were perceived as key success factors. Hence, we put forward that exploring synergies with academic research programs could represent a competitive advantage within digital transformation initiatives.

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