Requirements Engineering for ML-Enabled Systems: Status Quo and Problems

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Abstract

Machine Learning (ML) systems are increasingly common in companies seeking to improve products and processes. While literature suggests that Requirements Engineering (RE) can address challenges in ML-enabled systems, most empirical studies are isolated and lack generalizability. The goal of this dissertation is to enhance the empirical evidence on the intersection of RE and ML-enabled systems. For this purpose, we conducted an international survey with 188 respondents from 25 countries, using statistical and qualitative analyses to explore RE practices and challenges in ML projects. Our key findings include: (i) project leaders and data scientists primarily handle RE activities, (ii) interactive Notebooks are the dominant documentation format, (iii) data quality, model reliability, and explainability are the main non-functional requirements, (iv) challenges when developing such systems include managing customer expectations and aligning requirements with data, and (v) the main problems practitioners face are related to lack of business domain understanding, unclear goals and requirements, and low customer engagement. These results give us a wider picture of the adopted practices and the challenges in industrial scenarios. We put forward the need to adapt further and disseminate RE-related practices for engineering high-quality ML-enabled systems.

Keywords

Requirements Engineering, Machine Learning, Survey

1 Introduction

Companies from different sectors are increasingly incorporating Machine Learning (ML) components into their software systems. We refer to these software systems, where an ML component is part of a larger system, as ML-enabled systems. There are several challenges associated to engineering such systems, like addressing additional qualities properties (*e.g.,* fairness and explainability), dealing with a high degree of iterative experimentation, and facing unrealistic assumptions [9, 11].

Literature suggests that Requirements Engineering (RE) can help to address problems related to engineering ML-enabled systems [1, 11, 13]. However, research on this intersection mainly focuses on using ML techniques to support RE activities rather than exploring how RE can improve the development of ML-enabled systems [6]. Besides this shift of attention, the current state of empirical evidence on how RE is applied in practice in the context of ML-enabled systems is still weak and dominated by isolated studies.

In order to help addressing these issues, the goal of this dissertation is to investigate the state of practice and problems of RE for ML-enabled systems, helping to steer future research on the topic. In particular, we aim to provide insights regarding (i) roles that are typically in charge of requirements, (ii) which requirements are typically elicited and documented, (iii) which non-functional requirements typically play a major role in ML-enabled systems development, (iv) which RE activities are perceived as most difficult, and lastly (v) what RE-related problems do ML practitioners face. For this purpose, we conducted an international survey with the aim of understanding the current industrial RE practices and problems that practitioners face when developing ML-enabled systems. In total, 188 practitioners from 25 countries completely answered the survey.

2 Research Questions and Methodology

Given the previous studies [8, 9, 12, 13], we want to complement them by offering a wider understanding of the practical problems that can guide the advancement of new RE for ML techniques and their effective implementation in real-world scenarios. The goal of this dissertation is to characterize the current practices and problems experienced by practitioners in the requirements life cycle stage of ML-enabled system projects.

As presented in Figure 1, we can summarize our research method. We have a three-step based methodology, which includes: (i) a survey based on best practices of survey research [15]; (ii) the data collection, which professionals involved in building ML-enabled systems, including different activities, such as management, design, and development; and (iii) the data analysis procedures, that involved both quantitative analysis, through inferential statistics with resampling methods, and qualitative analysis using open and axial coding procedures from grounded theory [10].

Figure 1: Methodology summary.

The questionnaire, the collected data, and the quantitative and qualitative data analysis artifacts, including Python scripts for the bootstrapping statistics and graphs and the peer-reviewed qualitative coding spreadsheets, are available in our open science repository [4].

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3 Main Results and Discussion

The survey findings reveal an intriguing aspect within ML contexts: the distribution of roles in RE activities. Contrary to conventional expectations, the role of requirements engineers and business analysts appears less prominent as presented in Figure 2. Instead, a notable shift is observed, with project leaders and data scientists taking the lead in RE efforts. As the literature suggests that RE can help address problems related to engineering ML-enabled systems, this could point to the fact that software engineering practices are not yet well established within this domain. Nevertheless, the involvement of project leaders and data scientists as key RE contributors could reflect the nature of ML projects, where domain expertise and data-driven insights are pivotal. This shift in responsibilities raises questions about the evolving dynamics of cross-functional collaborations within ML endeavors and prompts further exploration into how such roles influence the shaping of ML-enabled systems.

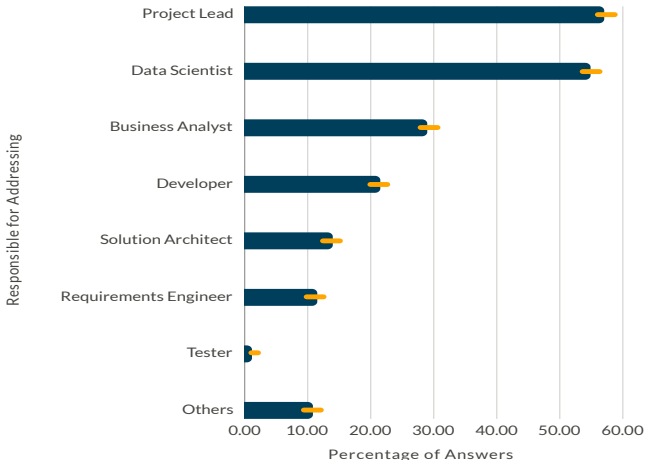

Figure 2: Roles addressing requirements of ML-enabled systems (N = 170)

The survey also revealed that practitioners typically use traditional requirements elicitation techniques (interviews, prototyping, scenarios, workshops, and observation) as presented in Figure 3. Comparing the results to the elicitation techniques reported for traditional RE [14], an observable difference is that requirements workshops are slightly less commonly used in ML contexts. This could be related to the absence of the requirements engineer, who is typically familiar with conducting such workshops, or to the lack of specific adaptations on such workshop formats for ML-enabled systems.

For requirements documentation, notebooks, which are interactive programming environments that can be used to process data and create ML models, appear to be the most used tool for documenting requirements as presented in Figure 4. Again, this could be a symptom of the absence of a requirements engineer and the lack of awareness of RE specification practices and tools. Furthermore, a proportion of almost 17% mentioned that requirements were not documented at all. Given that in conventional contexts, problems related to requirements are common causes of overall software project failure [7], this apparent lack of RE-related maturity may

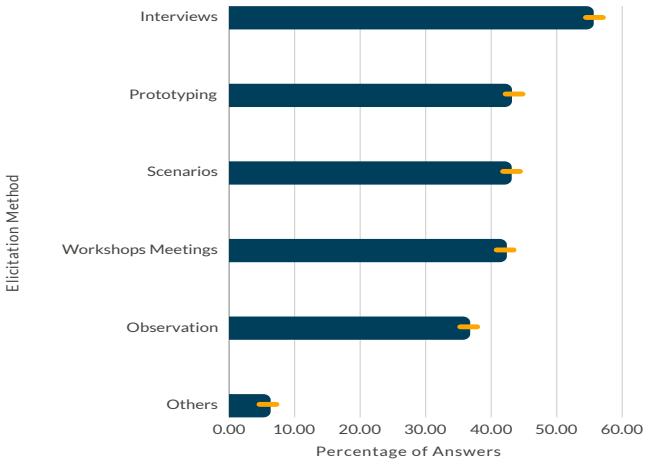

Figure 3: Requirements elicitation techniques of ML-enabled systems (N = 171)

also be causing pain in ML contexts. Traditional artifacts, such as user stories, requirements lists, prototypes, and use case models, are also used in the ML context, but significantly less than in the conventional software context [14]. Even specific approaches, such as the ML Canvas, do not relevantly represent a current practice for documenting the requirements of ML-enabled systems.

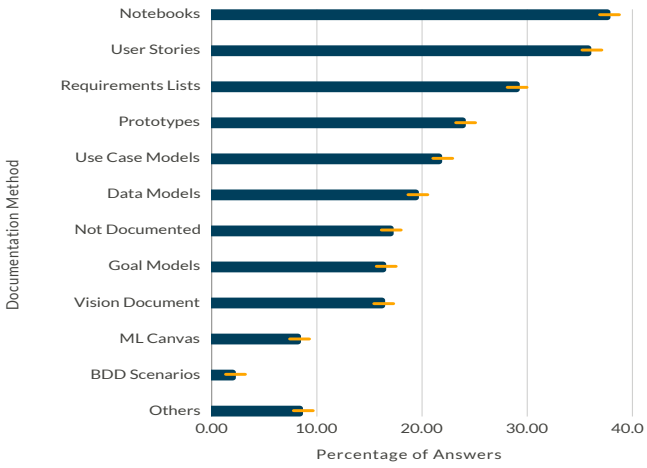

Figure 4: Requirements documentation of ML-enabled systems (N = 171)

Regarding NFRs, practitioners express considerable concerns with specific ML-related NFRs, such as data quality, model reliability, and model explainability, while also recognizing the significance of overall system-related NFRs. Nevertheless, more than 10% of practitioners do not even consider NFRs in their ML-enabled system projects. Again, given the potential negative impacts of missing NFRs on software-related projects [7], this can be seen as another indicator of the lack of overall awareness of the importance of RE in the industrial ML-enabled systems engineering context.

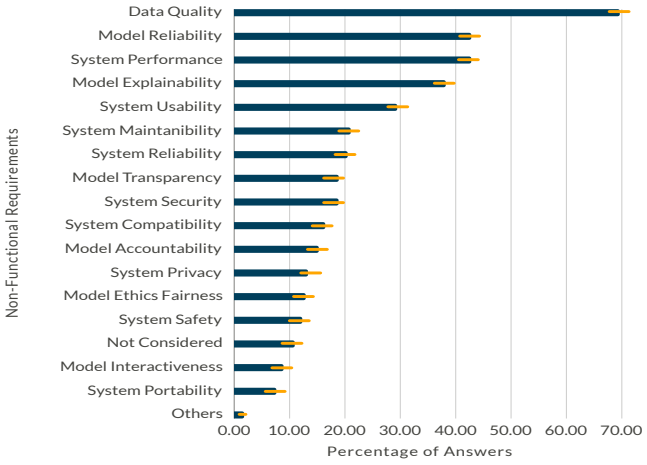

Figure 5: Critical non-functional requirements of ML-enabled systems (N = 169)

The survey also revealed the most difficult activities perceived by practitioners in defining requirements for ML-enabled systems. The difficulties reported by practitioners include managing customer expectations and aligning requirements with data, highlighting the importance of effective communication, a deep understanding of customer needs, and domain and technical expertise to bridge the gap between aspirations and technological feasibility.

Finally, we contributed to the RE-related problems faced by practitioners in ML-enabled system projects. The main issues relate to difficulties in problem and business understanding, managing expectations, and low customer or domain expert availability or engagement as presented in Figure 6. These issues clearly have comparable counterparts in the conventional RE problems [7]. As comparable problems may have comparable solutions, adopting established RE practices (or adaptations of such practices) may help improve ML-enabled system engineering.

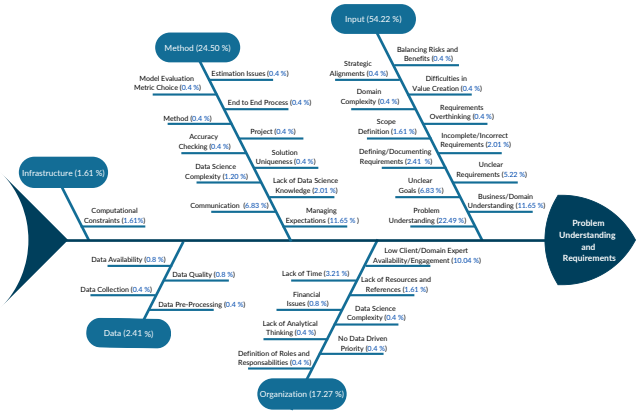

Figure 6: Main problems faced during problem understanding and requirements

4 Previous Work Reference

The original dissertation and the accepted papers of this research were published at the PUC-Rio Digital Library, Maxwell [3], PROFES 2023 [5], and SBES 2024 [2] respectively.

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