Digitalisation of Agriculture: Development and Evaluation of a Model-based Requirements Engineering Process

Chiara Mannari[1,2,*], Giorgio Oronzo Spagnolo[1], Manlio Bacco[1] and Alessio Malizia[2,3]

[1]*Institute of Information Science and Technologies "Alessandro Faedo" - ISTI, CNR, Pisa, Italy*

[2]*Computer Science Department, University of Pisa, Pisa, Italy*

[3]*Faculty of Logistics, Molde University College, Molde, Norway*

Abstract

[Context and Motivation] The requirements elicitation process for socio-technical systems requires the involvement of diverse stakeholders with different backgrounds and skills. In these contexts, effective communication between business analysts and stakeholders can be supported by model-based requirements engineering (MoDRE) strategies, which leverage diagrammatic notations as a means for information exchange. [Question/Problem] Several diagrams and approaches exist to facilitate MoDRE. However, empirical evidence on their applicability to real-world contexts with a relevant social component, and going through a process of digitalisation, is limited. Furthermore, existing approaches do not evaluate the *impact* that the deployment of a novel digital system has on the process and its actors. [Principal idea/Results] The research outlined in this paper aims to evaluate the joint usage of typical requirements engineer notations, namely i*, class diagrams, and business process models in the elicitation of requirements for socially-intensive systems that are going through a transformative digitalisation process. We apply these notations to represent the system-as-is, and the system-to-be, with the goal of also evaluating the impact of digitalisation. We focus on *living labs* (LL, i.e., networks of stakeholders participating in a socio-technical system) belonging to the agriculture domain, and provide a preliminary application on a farm that is introducing an AI-based irrigation system. [Contribution] The results show that effective communication with non-technical stakeholders is feasible with the envisioned approach. Although multiple iterations are required, agronomists and farmers are able to provide constructive feedback on the basis of the models. Furthermore, impacts in terms of additional/removed tasks and actors can be effectively characterised through business process models. As part of our overall project, we will refine the method, and then apply it in 20 living labs in the EU.

Keywords

requirements elicitation, socio-technical system, agriculture, living labs, process modelling

1. Introduction

Digitalisation in agriculture is a socio-technical process to be considered from multiple perspectives, such as social, economic, environmental, and technological. The focus on the introduction

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*Corresponding author

chiara.mannari@isti.cnr.it (C. Mannari); spagnolo@isti.cnr.it (G. O. Spagnolo); manlio.bacco@isti.cnr.it (M. Bacco); alessio.malizia@unipi.it (A. Malizia)

0000-0002-5488-4150 (C. Mannari); 0000-0000-0002-7771-0882 (G. O. Spagnolo); 0000-0001-6733-1873 (M. Bacco); 0000-0002-2601-7009 (A. Malizia)

and adoption of Information and Communication Technologies (ICT) — a specific class of technical tools — has brought to the development of the concept of *socio-cyber-physical* systems in [1], in which the relevance of the perspectives mentioned is considered as well. While there has always been great interest in the most innovative digital technologies, as emerges from [2] and [3], recent studies consider the impacts of the adoption of such technologies in real contexts, analysing drivers and barriers [4]. The EU-funded research project *Maximizing the co-benefits of agricultural digitalisation through conducive digital ecosystems* (CODECS), started in the late 2022, aims at evaluating the impact of digitalisation in agriculture by developing a method to map, model, and assess the context in which a digitalisation process occurs. The overarching ambition of CODECS is to improve the collective capacity of farmers to understand and adopt digital technologies as an enabler of sustainable and transformative change. To fulfil such objectives, an interdisciplinary research group and multiple living labs (LLs), the latter as key research units in the field, have been set up. LLs are networks of farmers, knowledge intermediaries, stakeholders, and policymakers addressing emerging challenges by co-developing user-friendly approaches, methods, and tools to assess the cost-benefits of technologies in real agricultural contexts. Thus, in order to generate a common understanding, two pillars are part of the project strategy: the adoption of a *conceptual framework* as a common language to carry on all the activities of the project, including theory building; and a *problem-based approach*, which gives the priority to the problem and encourages actors and stakeholders with different expertise to address it. The reference conceptual framework is the Ostrom's socio-ecological System (SES) framework [5], a multi-level scheme of concepts and variables to describe systems in terms of resources, such as natural ones, but also digital technologies and knowledge. Considering concepts such as resource systems, resource units, governance systems, and actors, Ostrom's framework will play an important role in enabling comparison, in the gathering of knowledge in multiple case studies (LLs in our case), and supporting the analysis of digital ecosystems (DEs), i.e. organized sets of digital, social-economic, organisational, and physical components that support the production, storage, communication, and use of digital technologies and data. The analysis will cover — but will not be limited to — the role of digital resources (data, application systems, etc.), digital resource systems (platforms, infrastructures, clouds, etc.), digital governance systems (data sharing and use regulation), actors and capabilities that are involved in the digitalisation process. The starting point for the analysis will be the *focal action situation* (FAS) defined by each LL, a condition in which individuals (acting on their own or as agents of formal organizations) interact with each other and thereby jointly affect outcomes that are differentially valued by those actors [5]. For the purposes of our research, we assume that the different components of a FAS leverage digital technologies for different outcomes. A key activity will be a task of *process modelling*, aiming at the creation of easy-to-read graphical representations of processes in FASs to describe and evaluate how the introduction of digital technologies may reshape a context (i.e., their *impacts*). The results of the analysis will be used as input for further activities, such as the description of DEs and the cost-benefits analysis. The models will represent a fraction of the FAS each LL will define, and they will be focused on the re-engineering of the processes, aiming at the representations of the processes *before* and *after* the introduction of digital technologies. The process modelling will be developed by applying model-based requirements engineering (MoDRE) strategies. This will contribute to fill the lack of empirical evidence on the applicability of MoDRE to real-world contexts with a relevant social component, as evidenced by [6]. The following sections present the methodology applied for a feasibility study on smart irrigation[1], and the discussion of some preliminary results. The methodology is to be considered tentative, as its definition is still in progress and may need to be tailored to the 20 different LLs.

2. Research Methodology

The overall objective of the project is to perform an analysis of the DEs from multiple perspectives. However, the transdisciplinarity of the research and the direct involvement of LLs bring complexity to information exchange. Communication challenges may arise at multiple levels: among different academic disciplines (economics, sociology, ecology, engineering, etc.); among different actors (researchers, farmers, intermediaries, stakeholders, policymakers, etc.); among domains and specialisations (water management, nutrient management, crop protection, livestock, etc.). Therefore, the purpose of our study is to address these research questions:

- **RQ1**: How to perform requirements elicitation in socio-technical systems in order to create representations that account for social relations and goals, structural elements, processes, and impacts of digitalisation?
- **RQ2**: What is the degree of user acceptance (usefulness, ease of use, and intention to use) of the devised elicitation procedures and system representations?

To answer RQ1, we will: 1) select graphical models from the MoDRE field, considering prominent notations for the representation of social interactions and goals, system components, processes, and impacts, and adapt the notations to maximise usefulness and understandability; 2) develop structured communication procedures between requirements analysts and stakeholders, with the goal of capturing elements of the systems and relations thereof, as well as impacts due to digitalisation. The objective of these procedures is to enable the representation of the system and its transformation according to the selected MoDRE notations. To achieve these goals, we will follow the design science paradigm [7] to come to a consolidated artefact consisting of a set of procedures and diagrams. Different sub-activities will be carried out with LLs, which will shape the community of local practices and will benefit from the research, while the FASs will contribute both to investigate the context of the problem and to refine the artefact itself. Furthermore, the Ostrom's framework adopted by the project as the common knowledge base will constitute the theoretical reference underpinning the research. To answer RQ2, the output of RQ1 will be evaluated by means of a multiple-case study [8], to be carried out within LLs of the CODECS consortium. To ensure that the representations produced are useful and understandable, we will evaluate them according to the Technology Acceptance Model (TAM) [9]. Specifically, we will use standard questionnaires to evaluate the constructs of Perceived Ease of Use (PEOU), Perceived Usefulness (PU) and Intention To Use (ITU), as done by other authors [10].

[1]The documentation produced is available at https://doi.org/10.5281/zenodo.7646686

3. A Pilot Study of Process Modelling Based on Smart Irrigation

As mentioned above, the activity is based on the application of MoDRE strategies to describe all the data of interest related to LLs in order to understand how current processes are re-engineered after the introduction of digital technologies. The transformation is emphasized by qualitatively highlighting the differences in the process-*as-is* (before) and in the process-*to-be* (after). To ensure the completeness of the representation, a set of languages has been so far identified and the following diagrams will be developed by each LL following a guided procedure:

- the *UML class diagram* will provide an overview of the classes, i. e. actors, tools, and infrastructures involved in the process-to-be and the relationships among them [11];
- the *i* goal diagram* will model the goals of the process-to-be focusing on the intentional, social, and strategic dimensions [12];
- the *BPMN process diagrams* will represent the detailed flow of the process and will allow comparisons between the overall process before (as-is) and after (to-be) the introduction of the digital technology [13][14][15].

The i* and UML diagrams only focus on the process-to-be in order to simplify the overall representation, considering that the core models to visualise the process transformation are the BPMN diagrams. This was a pragmatic decision of the authors.

In order to assess the modelling methodology, a feasibility study based on a smart irrigation system adopted on a pear orchard by Illuminati Frutta[2], a fruit farm in Tuscany, was analysed and some diagrams were drawn with the notations mentioned above. The adoption of a precise irrigation system, composed of a wireless sensor network (WSN) and a decision support system (DSS), has promising potential in terms of economic, productive, and environmental benefits.

Figure 1 contains the UML class diagram which provides an overview of the classes, i. e. actors, tools, and infrastructures involved in the precision irrigation system and the relationships between them, i.e., roles and actions performed. The new classes introduced by digital technology are in light blue. In Figure 2, the i* diagram represents the goals of the irrigation process. Highlighting actors, components, and activities performed in relation to the goals and qualities, the model focuses on the demonstration of the positive impact of the introduction of the new actor "DSS infrastructure" and its measurement activities in supporting the irrigation task of the farmer. Figure 3 is an overlap of two BPMN models: a first diagram describing the process before the introduction of technology, and a second diagram representing the precision irrigation system introduced by the DSS infrastructure. In the picture, the new participants, activities and gateways introduced by technology are in blue; in green the activities and gateways that do not change; in red the activities and gateways that are not present anymore. The aim of this visualisation is to provide an overview of the process re-engineering impacts. This is expected to be used for an in-depth *qualitative* discussion on the effects of digitalisation (novel/removed tasks, actors, consequences of the transformation, etc.) with the involved stakeholders.

The procedure adopted to define the models is as follows:

- The authors of the paper (computer scientists) visited the farm and dedicated half a day to interacting with a group of ten people who consisted of farmers, agronomists, and the owner of the farm.

[2] http://www.illuminatifrutta.it *last visited 9 February 2023*

- The agronomists were asked to write a document in natural language describing the system structure, and the automated process currently under development, especially describing the change with respect to a manual process.
- Based on the document, the first author created the diagrams. These were revised with experts in i*, class diagrams, and BPMN, and this led to 11 changes to better comply with the grammar of the notations (all changes are tracked in an Excel file, available in our replication package—see Footnote 1). This suggests that, also in future instances of the methodology, this step requires the involvement of experts to ensure that the diagrams are syntactically correct.
- The diagrams were used to further clarify certain aspects of the system in a 2-hours meeting with the agronomists. This led to 2 substantial changes in the diagrams, (new components and relationships in the UML), and the meeting showed that the agronomists clearly understood the notations and were able to provide feedback. The agronomist particularly appreciated the BPMN diagrams, but highlighted that the representations did not consider the process for setting the setup of the new system, not allowing for an analysis of the costs of the transition (e.g., training, pilot tests). Despite that, it was agreed not to include additional diagrams, in favour of leaner models focusing on the representation of the system before and after the introduction of digital technologies. The representation of the transition will however be considered in other tasks of the project.

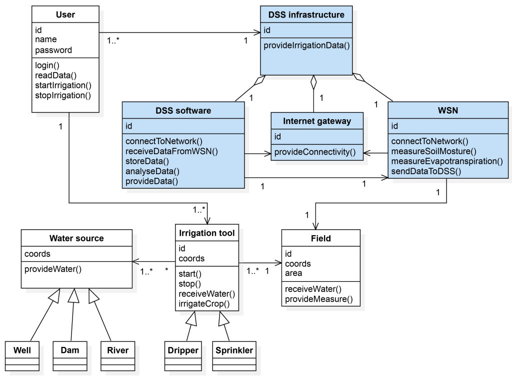

Figure 1: UML class diagram

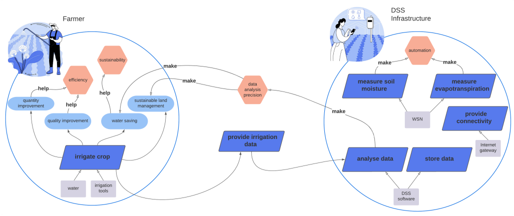

Figure 2: i* goal diagram

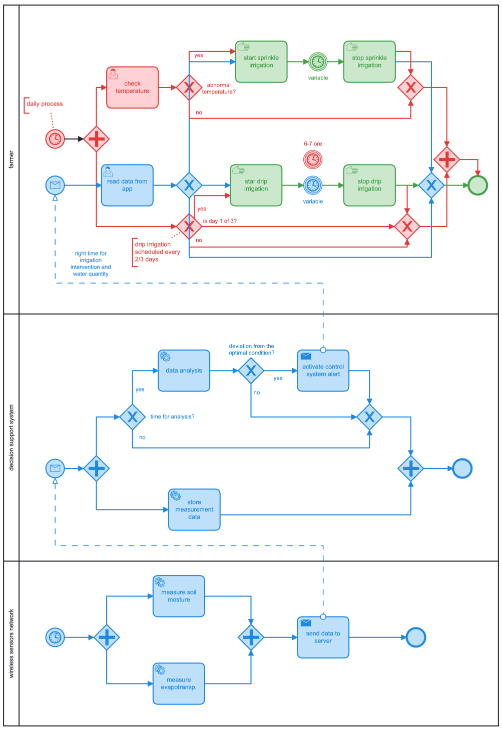

Figure 3: comparison of BPMN process diagrams

4. Current Stage and Road Map

The current stage of our research consists of the *requirements definition* step of the design science treatment targeted to RQ1. The feasibility study mentioned above represents the output of the *outline artefact* sub-activity, aimed at identifying the type of artefact to develop. The feasibility study, which includes the models described above as well as a proposal of the methodology to carry out the process modelling, was evaluated during a plenary meeting in order to complete the sub-activity of *requirements elicitation.* The methodology to carry out the process modelling is based on the procedure adopted for the development of the models. Some adjustments were made to comply with two major project constraints. The first is related to the data collection procedure, in fact, it is required that it will be performed by LLs in coordination with other project tasks in which data collection is foreseen. The second is the limitation of iterations necessary to correct the models. Such iterations, arising from questions triggered by the process modelling, are recorded in a working document keeping track of feedback and changes. On the one hand, iterations are fundamental for reaching precision and high levels of detail in the models; on the other, they are also time-consuming, requiring the availability of multiple actors. Eventually, a five-step methodology to carry out the process modelling has been agreed upon. The methodology is based on these steps: *1) data collection; 2) reporting; 3) check; 4) formalisation; 5) agreement.* Steps 1 and 2 will be performed by LLs together with LLs coordinators, steps 4 and 5 will be carried out by task leaders with LLs' support, while step 5 will be the final agreement between task leaders and LLs. Thus, the next stage will consist of the design and development of the artefact. Before starting the modelling, guidelines describing the activities to carry out for data collection, along with a training session, will be produced and provided to LL coordinators. Having clear guidelines is fundamental in order to collect the right information for creating correct representations of the systems. Guidelines for the production and creation of the models will be followed by further demonstration and evaluation steps. As a design science project, it will be carried out in an iterative way, moving back and forth between all the activities, adapting the models and the procedures to LLs needs and refining the overall process. The final phase will be devoted to answering RQ2, with the evaluation both of the system representations, and the overall methodology through standard questionnaires administered to the LLs.

5. Conclusions

This paper presents preliminary results arising from the ongoing research project EU CODECS. LLs involvement helps both to address emerging challenges related to the adoption of ICT and to perform research in real agricultural contexts. Diagrammatic notations are the common language for information exchange between different actors, and MoDRE strategies help to describe socio-technical systems. On the one hand, having a clear representation of the processes tailored to farmer's needs is fundamental to performing the technology assessment of such systems; on the other, the focus on the process re-engineering will allow describing the impacts of the introduction of digital technologies. Future challenges include the development and evaluation of a successful methodology for data collection and modelling, and additional models to tackle the *transition* phase between the *before* and *after* the introduction of technology.

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