UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL
INSTITUTO DE INFORMÁTICA
CURSO DE CIÊNCIA DA COMPUTAÇÃO

EMILY DO AMARAL CALVET PEREIRA

Business Process Model for the Interoperability Improvement in the Agriculture Domain with the Use of Digital Twins

Work presented in partial fulfillment of the requirements for the degree of Bachelor in Computer Science

Advisor: Prof[a]. Dr. Lucineia Heloisa Thom
Coadvisor: Rodrigo Meneses Porto Falcão

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UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL
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ABSTRACT

Agriculture is one of the most important practices for humanity and has been revolutionizing itself to keep up with the population growth and the new demands of the modern world and it is currently going through digital transformation. The fundamental data for the management of a farm originates from tasks performed by different machines or employees, systems of different providers and, are then, stored in a distributed manner and usually with non-standardized formats. That facilitates the occurrence of data incompatibilities and inconsistencies in a farm's processes, as a farmer commonly may need more than one system to manage all the specific steps involved. On this matter, the Fraunhofer Institute of Experimental Software Engineering (IESE) project Cognitive Agriculture, COGNAC, aims at the improvement of the interoperability between these distinct systems and machines by building an Agricultural Data Space (ADS) that implements the concept of Digital Twin. This work focuses on demonstrating with BPM that the use of DTs by COGNAC can improve the agriculture domain interoperability between these and other services. Such enhancement is demonstrated by applying the three steps - Process Discovery, Process Analysis, and Process Redesign - from the BPM lifecycle to a sugar beet farming process use case in Germany. First, modelling the as-is business process model without DT, analyzing it and then redesigning it into the to-be model accordingly with the DT integration. The analysis was made with the Waste Analysis methodology and identified the problems already pointed by the farmers, hence confirming them. Moreover, the redesign step shows a reduction on the number of tasks needed to be performed by the farmer and, thus, an improvement on the process data quality, interoperability and efficiency. Finally, a web farm management information system prototype capable of connecting to the DT was implemented to help validate the to-be model.

Keywords: BPM. business process management. BPMN. digital twin. agriculture. farm management information system. FMIS. interoperability.

Modelo de Processo de Negócio para a Melhoria da Interoperabilidade no Domínio da Agricultura com o uso de Gêmeos Digitais.

RESUMO

A agricultura é uma das práticas mais importantes para a humanidade e tem se revolucionado para acompanhar o crescimento da população e as novas exigências do mundo moderno, passando, atualmente, pela transformação digital. Os dados fundamentais para a gestão de uma fazenda originam-se de tarefas realizadas por diferentes máquinas ou trabalhadores, sistemas de diferentes provedores e então são armazenados de forma distribuída e geralmente com formatos não padronizados. Isto facilita a ocorrência de incompatibilidades e inconsistências de dados nos processos de uma fazenda, uma vez que um agricultor pode necessitar mais do que um sistema para gerir etapas específicas. Neste contexto, o projeto Cognitive Agriculture, COGNAC, do Instituto Fraunhofer de Engenharia de Software Experimental (IESE), visa a melhoria da interoperabilidade entre estes distintos sistemas e máquinas através da construção de um Espaço de Dados Agrícola (ADS) que implementa o conceito de Gêmeos Digitais. Este trabalho tem como objetivo demonstrar que a utilização de Gêmeos Digitais pelo COGNAC pode melhorar a interoperabilidade do domínio da agricultura entre estes e outros serviços. Esta melhoria é demonstrada através da aplicação das três etapas - Descoberta do Processo, Análise do Processo e Remodelagem do Processo - do ciclo de vida do BPM em um caso de uso do processo de cultivo da beterraba na Alemanha. Primeiro, o modelo de processo de negócio as-is, sem Gêmeos Digitais, é feito, analisado e, em seguida, remodelado no modelo to-be, de acordo com a integração dos Gêmeos Digitais. A análise foi feita com a metodologia de Análise de Resíduos (Waste Analysis) e identificou os problemas já apontados pelos agricultores, portanto os confirmando. Além disso, a etapa de remodelagem mostra uma redução do número de tarefas a serem realizadas pelo agricultor e uma melhoria da qualidade e interoperabilidade dos dados do processo. Finalmente, foi implementado um protótipo web de sistema de gestão de fazendas capaz de se conectar aos Gêmeos Digitais para ajudar a validar o modelo to-be.

Palavras-chave: BPM. gestão de processo de negócio. BPMN. agricultura. gêmeos digitais. sistema de gestão de fazenda. interoperabilidade. UFRGS.

LIST OF FIGURES

Figure 1.1 Change in cereal production, yield and land use, World, 1961 to 2018........10
Figure 1.2 This work's Methodology...13

Figure 2.1 Interview-Based Discovery Cycle 17
Figure 2.2 The Redesign Orbit of business process redesign methods...........................19
Figure 2.3 BPM Lifecycle..20
Figure 2.4 BPMN Events 22
Figure 2.5 BPMN Event Markers 22
Figure 2.6 BPMN Activities 22
Figure 2.7 BPMN Exclusive Gateway 23
Figure 2.8 BPMN Data Object Example 23
Figure 2.9 BPMN Object Connectors...24
Figure 2.10 BPMN Swimlanes Example 24
Figure 2.11 BPMN Artifacts...25
Figure 2.12 ADS as envisioned by Fraunhofer...30

Figure 3.1 Sugar Beet Farming As-Is 37
Figure 3.2 Sugar Beet Farming To-Be (With integration of the ADS Platform) 43

Figure 4.1 Basic FMIS - Authorization Flow 47
Figure 4.2 Basic FMIS Use Case Diagram...50
Figure 4.3 Basic FMIS Sequence Diagram...51
Figure 4.4 Basic FMIS Site Map 52
Figure 4.5 Basic FMIS Login 53
Figure 4.6 Basic FMIS Dashboard..53
Figure 4.7 Basic FMIS Fields List..54
Figure 4.8 Basic FMIS Field Management..55
Figure 4.9 Basic FMIS Field Administration...55
Figure 4.10 Basic FMIS Field Work Records...56
Figure 4.11 Basic FMIS Mobile Fields List 57
Figure 4.12 Basic FMIS Mobile Field Administration..57
Figure 4.13 Basic FMIS Mobile Field Work Records 57

LIST OF TABLES

Table 2.1 Related Works Comparison 32

Table 3.1 Sentence Template from Silva et al. (2019) 34
Table 3.2 Issue Register of Sugar Beet Planting As-Is Process 39

Table 4.1 Considered Libraries Pros and Cons 48
Table 4.2 Basic FMIS Main Frameworks and libraries.. 49

LIST OF ABBREVIATIONS AND ACRONYMS

BPM	Business Process Management
BPMN	Business Process Model Notation 2.0
7PMG	Seven Process Modeling Guidelines
FMIS	Farm Management Information System
DT	Digital Twin
ADS	Agricultural Data Space
OMG	Object Management Group
VRA	Variable Rate Application
GNSS	Global Navigation Satellite System
ERP	Enterprise Resource Planning
BPMS	Business Process Management System
IESE	Institute of Experimental Software Engineering

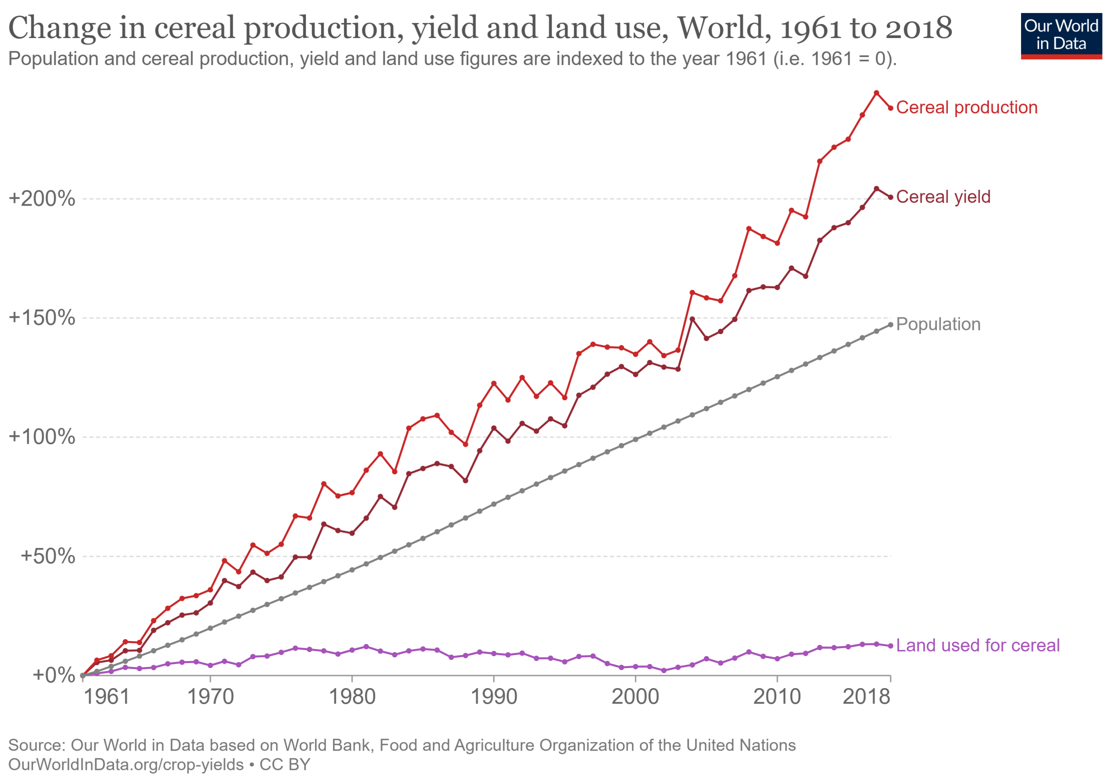
CONTENTS

1 INTRODUCTION..........10
1.1 Goal..........12
1.2 Main Contribution..........12
1.3 Text Organization..........13
2 BACKGROUND AND RELATED WORKS..........15
2.1 Business Process Management..........15
2.1.1 BPM Lifecycle..........16
2.1.2 Process Model Quality..........19
2.2 Business Process Model and Notation..........21
2.3 Precision Farming..........25
2.4 Farm Management Information System..........27
2.5 Digital Twin..........27
2.6 Cognitive Agriculture..........29
2.7 Related Works..........31
2.8 Chapter Summary..........32
3 SUGAR BEET FARMING PROCESS MODELLING..........33
3.1 Process Discovery..........33
3.2 Process Analysis..........38
3.3 Process Redesign..........39
3.4 Chapter Summary..........44
4 FMIS PROTOTYPE..........45
4.1 Design Decisions..........45
4.1.1 Architecture..........45
4.1.2 Technologies..........46
4.2 Functionalities..........48
4.3 Demonstration..........52
4.4 Chapter Summary..........56
5 CONCLUSION..........58
REFERENCES..........60

1 INTRODUCTION

As one of the most important practices for the human survival in the world, agriculture has gone through several revolutions in order to adapt itself to better supply all the emerging demands. The increasing population growth means that there have been always more people to be fed, but not necessarily that there is more farmland in use (OURWORLDINDATA, 2021). Nevertheless, as depicted in Figure 1.1, the crop farming managed to increase its crop production without having to increase its land use, stating that there was also ongoing research and optimization of the agriculture techniques and resources in order to achieve this.

Figure 1.1 – Change in cereal production, yield and land use, World, 1961 to 2018



Source: OurWorldInData (2021)

The population growth is not the only challenge posed to agriculture through time. There is also the demand for high-quality groceries, traceable food and more sustainability, which implies that the government of each country requires the farms to comply with health and sustainability laws that control the amount of pesticides and fertilizers among other compounds that can be utilized in a crop (DOERR; NACHTMANN, to appear). These challenges are tackled by the appearance of Precision Farming, specially in the

1990s when the integration of Global Navigation Satellite Systems (GNSS) into tractors and other farm machinery enabled the management of product application amount in specific field locations, named Variable Rate Application (VRA) (DOERR; NACHTMANN, to appear). The position monitoring, along with various advanced sensing technologies and software analysis, also enable much more precise soil and plant analysis, thus providing the farmer with important information that can give them much better decision support. The main advantages of it are mainly more efficient processes, costs savings, better quality yields and healthier soil for future crops and the generations to come (BONGIOVANNI; LOWENBERG-DEBOER, 2004).

Nowadays, in Europe, the farms have sensors all around gathering data about weather, soil composition, plants conditions, machinery and so on ((EIP-AGRI), 2015). All this data must be analyzed and stored in agricultural domain specific systems, usually Farm Management Information Systems (FMIS) that help the farmer to understand what the data means, what can be done about it, therefore also contributing with decision support for the next steps to be taken. Another key use of the FMIS is the management of the farm's resources and planning of tasks, so the activities can be tracked.

The technical evolution and digitization in agriculture grew faster than the standardization of its data formats. Therefore, several companies developed their own agriculture specific software with the data formats they considered best for it, resulting in a cluster of systems that are not interoperable with each other (IESE, 2020). Farms have diverse processes that are tackled by specific systems, meaning that a farmer needs to deal with more than one system to manage their farm as a whole. Furthermore, the farm data becomes distributed since these systems are not encouraged to share data between each other as their providers seek to offer complete systems of their own ((EIP-AGRI), 2015). Consequently, leading to data inconsistencies problems in the future and to more effort for the farmer to keep them in sync.

In light of these challenges, the Fraunhofer Institute for Experimental Software Engineering (IESE) created the research project Cognitive Agriculture (IESE, 2019), COGNAC for short, with the intent to build an Agricultural Data Space (ADS) to enable a digital ecosystem for agriculture (IESE, 2021a). The ADS can be seen as a coexistence of different digital ecosystems, that compete with each other, but are linked to a common digital infrastructure in order to be largely interoperable. The core objectives of the project are to provide interoperability and data sovereignty through the ADS. Moreover, the project applies the already consolidated Industry 4.0 concept *Digital Twins* (DT) in the agriculture domain, initially with digital Field Twins for crop farming. A DT is a digital version of an asset with a two-way connection to its physical twin. The ADS is enabled with the help of a platform, the ADS Platform (IESE, 2021b). The ADS Platform is proposed to provide the farmer with data sovereignty, so they can choose with which systems they want to share their data and can change this configuration whenever they want. Also, the platform provides central data storage through the use of DTs. With the integration of DTs the systems have access to historical data to perform analysis, forecasts and digital simulations and share their services with each other to boost the farm productivity and sustainability (IESE, 2021c). One of the use cases studied by COGNAC is about the sugar beet farming process. In this work, this use case will be processed through the Business Process Management (BPM) Lifecycle to validate the improvement of the interoperability by the integration of the ADS Platform and the DTs.

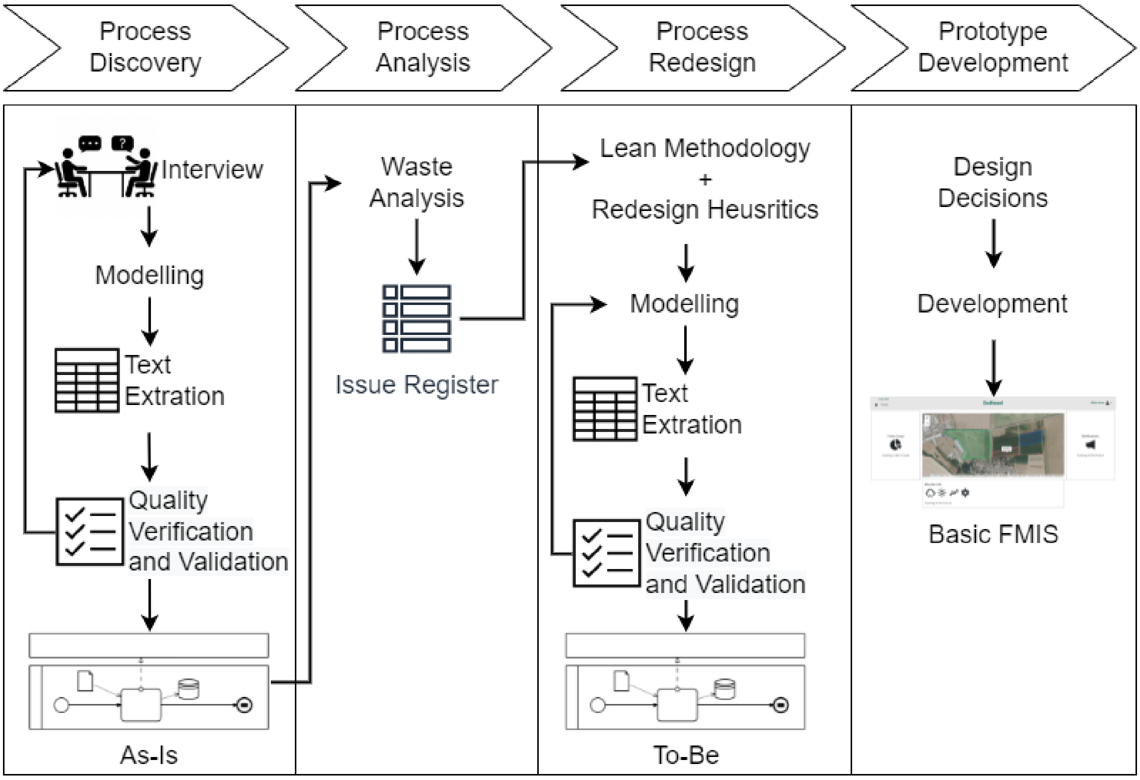
1.1 Goal

The main goal of this work is to contribute to the validation and demonstration of the concept presented by the COGNAC project to introduce the DT approach in the agriculture domain, along with the creation of the ADS Platform to build a largely interoperable digital ecosystem.

1.2 Main Contribution

This work has as main contribution the execution of three steps of the BPM Lifecycle (Process Discovery, Process Analysis and Process Redesign) in the context of the business process of sugar beet farming as it is commonly done in Germany, which is one of the cases studied by the COGNAC project. In the Process Discovery step, a cycle composed by interviews with a agriculture domain expert from Fraunhofer IESE, modelling of the process discussed, extraction of text description of the model and quality verification and validation is performed to result in the *as-is* model of the sugar beet farming. Next, in the Process Analysis step, the as-is model is analyzed to find its vulnerabilities and points of improvements and these findings are documented in an Issue Register. Then, in the Process Redesign step, the Lean methodology is used along with the best fitting redesign heuristics to redesign the as-is model according to its improvements points and to COGNAC's integration of the ADS Platform and the Field Twin approach. This step follows a similar cycle of the discovery step, containing the modelling, the text extraction from the model and the quality verification and validation of it resulting on the *to-be* model. The modelling on both steps was done with the Business Process Model and Notation (BPMN 2.0) (OMG, 2010). Furthermore, a web-based FMIS prototype, Basic FMIS, is implemented by the author to collaborate with the project's validation by demonstrating the Field Twin data management and visualization. The methodology process of this work can be viewed in Figure 1.2.

Figure 1.2 – This work's Methodology



Source: The Author

1.3 Text Organization

The text is organized as follows. Chapter 2 covers all the theoretical fundamentals discussed and implemented in this work by defining the concepts: BPM, BPMN, DT, Precision Farming, FMIS; and the COGNAC project; Next, in Chapter 3 the business process of sugar beet farming is taken into the BPM Process Discovery, Process Analysis and Process Redesign steps through BPMN modelling to identify its vulnerabilities, points of potential improvements, and then it is redesigned in accordance to the findings; Subsequently, the implementation of a web-based FMIS prototype is detailed and demonstrated in Chapter 4; Finally, Chapter 5 gives the author's conclusions and comments on future work about this work.

2 BACKGROUND AND RELATED WORKS

This chapter presents the basis of BPM and the BPMN 2.0 notation used in this work to model the use case's process. Moreover, this chapter defines the core concepts utilized in this work - Precision Farming, FMIS and DT - along with the description of the COGNAC project. Finally, the chapter discusses related work.

2.1 Business Process Management

BPM is a discipline that involves methods, principles and tools for not only discovering the processes within an organization, but for analyzing, monitoring and improving them in order to gain the best value to the target stakeholders. The need for management of business processes can be traced back to the industrial revolution, where several employees worked together sequentially for the construction of a single product, each with one or more very specific tasks (DUMAS et al., 2018). To ensure the best performance and efficiency, the role of a manager was created, so they could monitor the whole process, adjust any of the tasks if needed and align results with other sections of the production. The result of the combination of the tasks is the product of a company, and BPM is very useful to organize them and understand how they relate to each other (WESKE, 2012).

A *process* is a chronological sequence composed of a number of *events* and *activities* performed by *actors*. An event is an element that has no duration and triggers another activity. Meanwhile, an activity takes time. It can be a series of documentation checks or, if it is only one effort, i.e. single and atomic unit of work - e.g. transporting a resource from one department to another-, it can be called a *task* (DUMAS et al., 2018). A process may also include:

- *Decision points*: situations in time when a decision is made about the direction of the activities and can affect the outcome of the whole process;
- *Physical Objects*: e.g. equipments and paper documents;
- *Informational Objects*: such as digital documents and records;

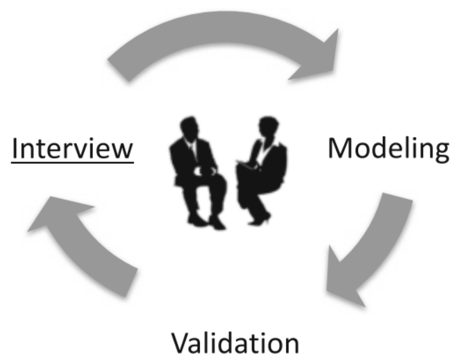
2.1.1 BPM Lifecycle

As defined by Dumas et al. (2018), the BPM lifecycle comprises 6 phases named *Process Identification, Process Discovery, Process Analysis, Process Redesign, Process Implementation* and *Process Monitoring*. After the process identification, all phases should be performed continuously in a cycle to ensure stability, considering that with time any good process without any maintenance can become a bad process. The phases are described below based on (DUMAS et al., 2018) and can be visualized in Figure 2.3.

Process Identification is the initial phase where a given problem is addressed by the recognition of the processes relevant to it, followed by the mapping of their relationships resulting in a *process architecture*. This process architecture provides a general look of the organization's processes and helps identify the relevant processes that should be taken further into the subsequent phases. During this phase, it is usually also done the identification of the *process performance measures*. Usually, the measures relate to time, cost, quality and flexibility, but not all of them need to be used together. Time is used based on an activities duration and can be summed for the whole process for overall analysis. Similarly, cost is measured by the element's cost, could be of an activity or of an object, produced or required. Quality can be calculated based on error frequency and flexibility by the consistency of the process outcome even during conditions changes, planned or unplanned.

Process Discovery aims at understanding and modelling the identified processes in detail. There are three main method categories for information gathering: *Evidence-Based Discovery, Interview-Based Discovery* and *Workshop-Based Discovery*. The first one collects the process information according to documentation, on-site observation or by automated process execution event logs. The second depends on the collaboration of process participants and domain experts during an interview-modelling-validation cycle. It is a method that takes time and effort, but it provides valuable insight into how the process is seen and done by its participants. This is the method utilized in this work, and Figure 2.1 illustrates this cycle. The third, Workshop-Based Discovery, has the advantage of involving more than one domain expert at a time, thus resolving inconsistencies on-the-go. It is also time and effort consuming and sometimes harder to facilitate due to calendar shock of the participants. From this phase, a process model is generated in a diagram form that represents the discovered process, called *as-is*. The model can be accompanied by a text description to avoid any misconceptions that may arise and describe the elements in detail if needed. It is best to model the processes in a diagram made with a modelling language agreed between the stakeholders to ensure no free-form text related ambiguities exist. There are several modelling languages, among Unified Modeling Language (UML), Event-driven Process Chains (EPCs), but the most widely-used today for BPM is the standard BPMN that is the one used in this work and detailed further later in this chapter.

Figure 2.1 – Interview-Based Discovery Cycle



Source: (DUMAS et al., 2018)

Process Analysis has two techniques categories, *quantitative* and *qualitative*. In the quantitative techniques is where the process performance measures can be used to analyze the as-is process quantitatively and identify its issues, so then they can be documented, prioritized and investigated to be solved. For example, if the most important measure is time, the analyst needs to gather information on how much time each activity takes and assert if it is damaging or not to the value the outcome of the considered process gives. The qualitative approaches target to find issues that impact the process in a manner difficult to quantify, for example, customer satisfaction or long-term partner relationships. The most used techniques are *Value-Added Analysis* and *Waste Analysis*, both defined in the *Toyota Production System* (TPS) developed in the 1970s. The first, seeks to categorize each activity based on the value it adds to the client of the process, focusing on the activities that are indispensable for the process. The second, is the one used in this work, and can be thought of as the inverse of the Value-Added approach, as it focuses on finding activities that are dispensable from the process. This approach was chosen due to its independence of the activities measurements of, for example, time and cost which are very specific to each farm and, thus, hard to specify.This method aims at finding waste in the process that can be reduced or eliminated completely. There are seven waste categories that Dumas et al. (2018) grouped into three:

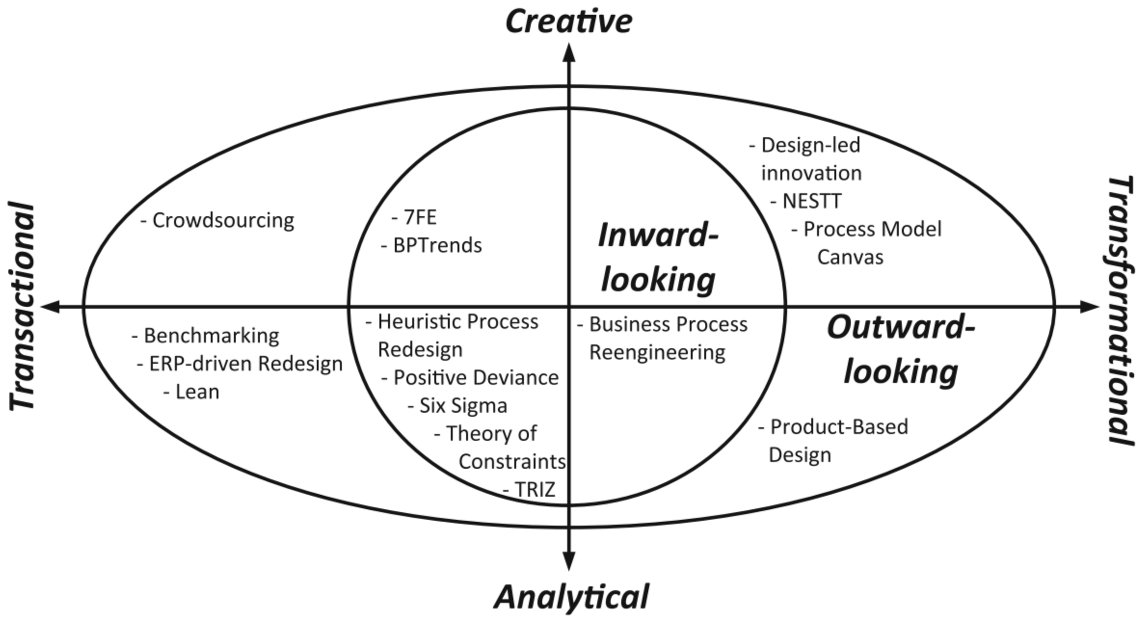
- Move: *transportation* and *motion*, waste related to movement;
- Hold: *inventory* and *waiting*, waste caused by holding something;
- Overdo: *defects, overprocessing* and *overproduction*, waste created by doing more than it is necessary to deliver the value to the client of the process.

Process Redesign, also known as process improvement, uses the documented issues found in the previous phase and focuses on identifying and evaluating possible solutions based on the chosen methodology. As presented by Dumas et al. (2018), there is a whole spectrum of methods, called the Redesign Orbit, to be chosen from, according to each organization's case. The methods can be either *Transactional* or *Transformational*, *Creative* or *Analytical*, *Inward-looking* or *Outward-looking*. Meaning, this orbit has three dimensions and a method can be at one of the two types just mentioned of each dimension. The Redesign Orbit is shown in Figure 2.2. Transactional methods take the current process as an initial point of examination and aim at a gradual overall improvement. On the other hand, transformational methods seek a revolutionary innovation for the organization, usually by building a whole new process. The difference between creative and analytical methods is that, while the first utilizes mostly human creativity with group activities as, for example, workshops; the second has a mathematical basis which uses quantitative techniques to analyze the process and aid the generation of alternatives. Finally, an inward-looking method takes the viewpoint of the organization and an outward-looking method has an outsider's perspective, e.g. a customer or a third-party organization. The result of this stage is the process remodeled with the elected best solutions to the organization's problem, called *to-be*.

Process Implementation's purpose is to actually implement the changes needed to execute the to-be process. This phase involves organizational change management and automation. The first one concerns the training of the organization's staff for the adaptation to the new activities to be done. This is a field on its own, very intrinsic to human resources management. The automation is about the development or upgrade of the information system used to support the to-be business process. This can be a very challenging task due to its costs and also if it relies on the support of systems maintained by other organizations.

Process Monitoring is the last phase and aims at avoiding the degradation of the process. Whilst in the execution of the new process, relevant data is collected and evaluated according to the expected performance, quality set to assert if the process is still providing the best value to the organization. If the expectations of the process are not

Figure 2.2 – The Redesign Orbit of business process redesign methods



Source: (DUMAS et al., 2018)

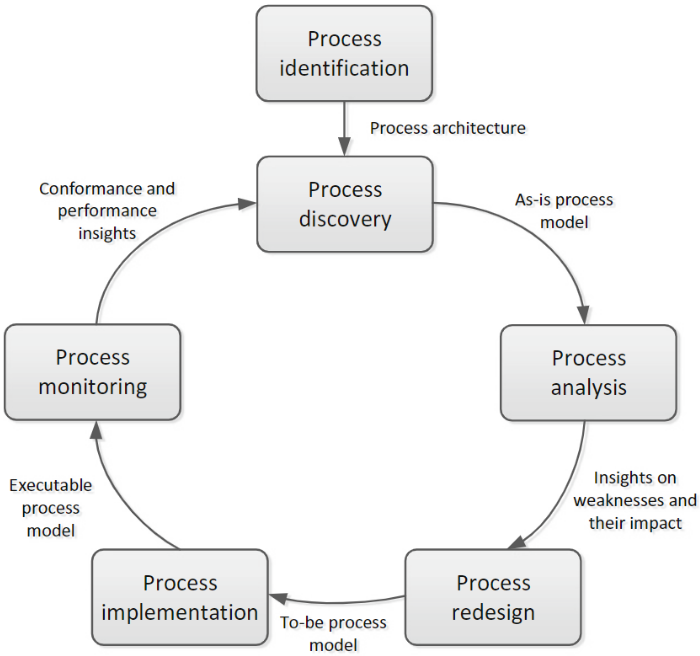
being met, or if new issues arise, the BPM cycle should start again and discover the new best process to be implemented.

2.1.2 Process Model Quality

There are seven quality aspects that can be analyzed in a process model (KROGSTIE, 2012). However, this work focuses on three main quality aspects: syntactic, semantic and pragmatic quality. Of each, respectively, the assurance procedure is called: verification, validation and certification.

Syntactic quality is divided into two different types of rules. One of them is *structural rules*, which regards to how the model connects elements related to each other. This work follows the structural rules listed for BPMN in (DUMAS et al., 2018). The other is *behavioral rules*, that relates to how a process can be instantiated, meaning that it takes into account how a process acts through its execution. A process instance should always complete a process. Therefore, *deadlocks* (an instance that cannot progress through the process), *livelocks* (an instance stuck in a loop), *lacks of synchronization* (poor use of gateways that split the instance and does not join it again properly) and *dead activities* (unreachable activities) have to be avoided and solved in a process model, so it can be

Figure 2.3 – BPM Lifecycle



Source: (DUMAS et al., 2018)

considered *behaviorally correct* or *sound*. This definition only regards the control-flow of the model and not if the messages and data inputs and outputs are accurate.

Semantic quality is more complicated to check since it has no specific rules to be followed, it is related to the compatibility of the model to its real-world process, thus it should be checked by talking it through with one of the participants of the process or the domain expert. It can be divided into two aspects as well: *validity* and *completeness*. A model is valid when its statements are correct in regard to its real-world process, and it is complete when it contains all the remarks relevant to the process.

Pragmatic quality refers to how the model can be useful for its purposes, hence its usage should be known beforehand. As it is related to how people will be using the model, aspects as *understandability, learning* and *maintainability* are between those that should be analyzed in a *Certification* operation. Structuring the model so that it becomes consistent through its flow, less hard to follow and adhering to naming conventions are some tasks to achieve pragmatic quality.

Complying to modelling guidelines helps to improve the pragmatic quality of a model by making it more consistent and standardized, therefore more reusable as well. This work follows the *Seven Process Modeling Guidelines (7PMG)* guidelines defined by

Mendling, Reijers and Aalst (2008) and also the guidelines defined by Avila and Thom (2019). Both of them define rules to prevent the model of getting too large or too confused to understand, and propose naming conventions for the elements to avoid language ambiguities.

2.2 Business Process Model and Notation

BPMN is the standard released by the Object Management Group (OMG), a not-for-profit technology standards consortium composed by vendors, end-users, academic institutions and government agencies. Its latest version, BPMN 2.0, was adopted in December 2010 (OMG, 2021). It is a flow-chart based notation created in agreement with several modeling tools vendors to use a single notation to benefit the end-user and training. It is meant to be methodology agnostic, meaning the level of detail and the purpose of the modeling is influenced by the methodology chosen by the analyst and that BPMN can be as complex or as simple as it needs to be (IBM, 2006). BPMN has 5 elements categories: *Flow Objects, Data, Connecting Objects, Swimlanes* and *Artifacts*. The categories are described below with focus on the elements used in this work based on the BPMN 2.0 specification (OMG, 2010).

Flow Objects are the main elements to define the behavior of the business process, and they are composed by *Events, Activities* and *Gateways*. An *Event* is an atomic (without time duration) thing that happens during a process and can *trigger* or *result* in something. It is represented by a circle with open center to permit the use of markers to differentiate between various triggers and results types. As represented in Figure 2.4, there are three types of events, Start, Intermediate and End. They have all basically self-explanatory names, implying that the Start event indicates where a process starts; the End event points where a process ends; and the Intermediate marks where something that affects the flow of the process happens, but not starts or ends it. The start event has triggers ("catch") and the end event has a result ("throw"), while the intermediate events can catch or throw triggers as shown in Figure 2.5. A message trigger event implies that a message was received from a process participant, and it triggers the start of a process (start event) or of an activity (intermediate event). Similarly, a message result means a message is sent to another process party. Furthermore, a timer event implies a specific time-date or cycle can be set to trigger the start of a process (start event) or of an activity (intermediate event).

Figure 2.4 – BPMN Events

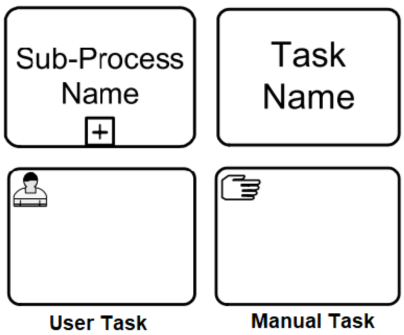
Source: (IBM, 2006)

Figure 2.5 – BPMN Event Markers

Source: (OMG, 2010)

Activities, represented by a rounded rectangle, are work performed by a process actor that takes some time, and they can be divided into two sub-categories, *Task* and *Sub-Process*. A Task is an action that cannot be broken down to a finer level of detail. Similarly to the events, markers can also be added to the task to facilitate the understanding of the task type. In this work, the task types used are: User Tasks and Manual Tasks. Both of them are performed by a human, but a User Task is an activity executed with the assistance of a software application through a UI, while a Manual Task is done entirely by the person performing it. A Sub-Process is an activity that is described in more detail in the model by a sub-set of activities, and can be expanded by clicking the plus sign on the lower part of the rectangle. The activities are represented in Figure 2.6.

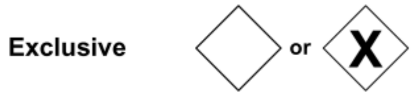
Figure 2.6 – BPMN Activities



Source: The Author

Gateways are used to control how the process diverges and converges during its flow. They are represented by a diamond shape and their internal markers define the type of behavior they have. The *Exclusive* type is used in this work, which represents a decision on the process path where only one way can be chosen for the current process instance in execution based on the decision made on the gateway. Figure 2.7 shows the representation of an Exclusive gateway. A usage example can also be seen on Figure 2.8.

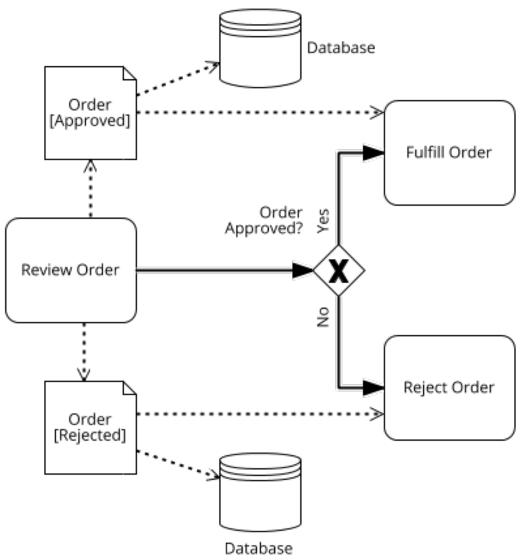
Figure 2.7 – BPMN Exclusive Gateway



Source: (OMG, 2010)

Data is represented by data objects that demonstrate how data and documents are used or produced within a process. They can define inputs and outputs while also having a state to present how they may have changed. In this work the data objects represent digital information related to a field relevant for the farm's processes, as field geographic data, target and actual applications map. A *data store* is a container for data objects that need to be persisted for longer than a process duration represented by a cylinder, it can be a physical cabinet or, as in this work, a database. A usage example of data objects is shown in Figure 2.8.

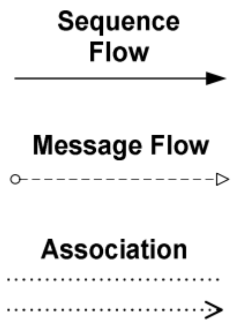
Figure 2.8 – BPMN Data Object Example



Source: The Author

Connecting Objects connect the Flow Objects to each other or to information by linking them with arrows or lines. They are divided into 3 sub-categories. The first is *Sequence Flow*, which depicts the order of the activities. The second is *Message Flow*, that demonstrates the messages exchanged between participants of a process. Lastly, the third is *Association*, that represents the link of the information and artifacts to the other elements. The association can be directed when appropriate.

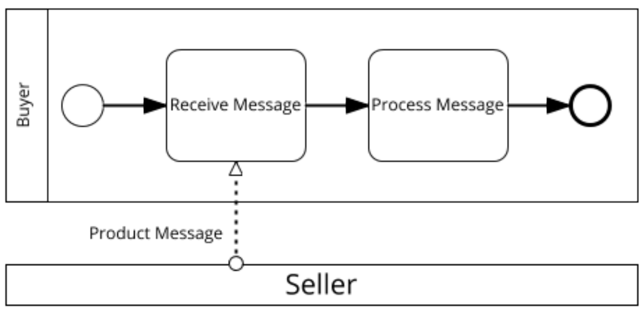
Figure 2.9 – BPMN Object Connectors



Source: (IBM, 2006)

Swimlanes were created to help distinguish the roles and their interaction within a process. They can be *Pools* and *Lanes*. Pools represent participants in a Business Process Diagram, as a role (e.g., "customer") or as a business entity (e.g., "OMG"). They have the possibility to be simply a black box or to contain a process. The interaction between pools is taken care of solely by the Message Flow. A Lane is a sub-partition in a process, occasionally within a Pool, representing an organizational role (e.g., "manager"). The Sequence Flow can cross through Lanes. Figure 2.10 shows an example of Swimlanes in use.

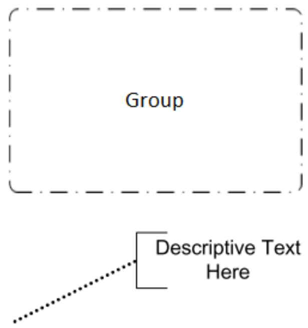
Figure 2.10 – BPMN Swimlanes Example



Source: The Author

Artifacts can be extended by modelers and modeling tools as long as the new shapes do not conflict with already existing shapes. The specified set of artifacts contains *Group* and *Text Annotation*. A Group is used to delimit elements of the same category in a process for documentation and analysis purposes. The category name appears as the group label, and the Sequence Flow is not affected by it. Text Annotations simply serve the modeler to add more information about an element to the reader. Both artifacts are shown in Figure 2.11.

Figure 2.11 – BPMN Artifacts



Source: (IBM, 2006)

2.3 Precision Farming

Precision farming for arable farming, which is the focus of this work, is a management concept coined in the 1990s (BLACKMORE et al., 1995) with the emergence of the GNSS and its integration to farming tractors enabling the farmers to control in real time how much product or seed is handled in which part of the field ((EIP-AGRI), 2015). This is to this day the most common use of precision farming in arable farming, however precision farming encompasses much more. Precision farming is based on observing, measuring and responding in near-real time to variations occurring inside and outside crops, fields and animals. This means having sensors that can observe, for example, soil nutrients, composition, weather information, plants status and animals conditions and share this information so that it can be analyzed by a specialized software or analyst. In accordance with the result, the farmer is able to take the appropriate actions to respond to it. Precision farming can be thought of "In the right place at the right time doing the right thing" (DOERR; NACHTMANN, to appear). This type of precision in farm management can bring multiple benefits to the farm and to the world. Exclusively by facilitating the application of product, being it pesticide or fertilizer, solely where it is needed and when it is needed, it provides cost reduction, healthier yields, healthier soils for future crops and water saving. This is known as VRA, one of the most used practices within precision farming, and its main challenge is to correctly understand and respond to the measured variations ((EIP-AGRI), 2015).

It is evident that precision farming is closely related to sustainability, a notion that the environment should be taken care of so that it can be delivered to future generations without degradation and even in better condition if possible. With precision farming, several concerns can be addressed and mitigated, those include: climate change, water pollution, increasing resistance of pests to biocides, excessive killing of beneficial species by pesticides, growing food supply demand, work safety, among others (BONGIOVANNI; LOWENBERG-DEBOER, 2004). Hence, the large adoption of precision farming practices and tools by farmers and the further development of precision farming applications with standardized and integrated data is of great importance.

The large adoption of precision farming is still challenged by several factors. One of them is the acceptance of new techniques and tools by the farmers. Farmers usually lack the knowledge, trust or the investment power to adopt new precision farming practices (DOERR; NACHTMANN, to appear). Furthermore, most of the precision farming applications have not yet strongly demonstrated their utility or may not be sufficiently user-friendly ((EIP-AGRI), 2015). Another factor is the urgent need for data management and compatibility, given that nowadays farms have increasing numbers of sensors all around, delivering a big amount of different data. All this data must be processed, stored and, preferably, interoperable between services. Surely, the data should be properly secured with data protection, which is also a field that needs improvement in this topic. Most current applications are developed without the use of international organizations standards, and hardware and software providers aim at building complete systems of their own instead of being encouraged to share data ((EIP-AGRI), 2015). Often, systems do not even share data among other systems on the same farm, which only complicates the farm's processes. The competition between companies that causes this disagreement on sharing data is still ongoing, but there are improvements towards a mediation and development of digital ecosystems to facilitate the integration of precision farming not only for big farms but for small farms as well.

2.4 Farm Management Information System

FMISs are one of the tools that enable and also have been pushed by the progress of precision farming, but one of the few that are actually designed for the agriculture domain. A FMIS can be seen as an Enterprise Resource Planning (ERP) software for agricultural activities, as it is designed to store and manage farms, fields, machinery, employees and other farm resources (DOERR; NACHTMANN, to appear). Since the complexity of the agriculture domain is great, a FMIS can usually focus on one or more subdomains, for example, livestock or arable farming (TUMMERS; KASSAHUN; TEKINERDOGAN, 2021). Examples of crop farming FMISs are: 365FarmNet [1] and MyEasyFarm[2].

Just like ERPs for companies, FMISs provide great value in supporting farmers in the decision-making processes. By facilitating to organize, analyze and control several important factors in farm operations, the ambiguities and loss of data are reduced and the planning and control of the production process are benefitted, thus also improving the performance of the farm. Furthermore, cost reduction is also achieved due to the better control and monitoring of the activities (CARRER et al., 2015).

As mentioned previously in this chapter, many applications are implemented without the intent of sharing or being compatible with data of applications from other providers. This is the case also with some FMISs. In order to support precision farming, a FMIS must be able to handle, most importantly, standardized data formats and to share data with other services that can provide precision farming value, in this manner facilitating interoperability while also complying to data protection and usage rules agreed with the farmer (NIKKILAE; SEILONEN; KOSKINEN, 2010).

2.5 Digital Twin

With the advances of technology in areas as Internet of Things, Big Data analytics, Artificial Intelligence and Cloud Computing, the convergence of the physical and virtual worlds becomes increasingly palpable (QI et al., 2021). The DT first appeared as a new concept in a presentation about Product Lifecycle Management by Grieves in 2003, a time when those technologies were still in development (TAO et al., 2019a). Nevertheless, the vision of a virtual model enhancing product lifecycle management was already created

[1] https://www.365farmnet.com/
[2] https://www.myeasyfarm.com/

and growing until 2012 when it arose strongly due to NASA's new definition and evident benefits to aircraft structural life monitoring (TAO et al., 2019b).

To this day there is still no definite definition of a DT, however in this work, as in (DOERR; NACHTMANN, to appear), it is taken as "an integrated multiphysics, multiscale, probabilistic simulation of an as-built vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its corresponding [...] twin" as defined by Glaessgen and Stargel (2012). Essentially, a DT determines the existence of a physical entity and its complete digital representation in total communication harmony, sharing data through bidirectional interactions (QI et al., 2021). Meaning that everything that happens in one twin has to be replicated in near real-time on its other twin. It is an ongoing cycle of monitoring status and analyzing it to recognize complexities, detect irregular behaviors, simulate changes, predict events and so on towards the collective evolution of the twins. For example, previously simulated tasks can be triggered in the virtual twin and then performed on its physical twin. There is lots of data and knowledge of the physical world of the real entity involved to ensure that the virtual entity is as true as it can get to its physical twin. Through the analysis of the data history - e.g. past problems -, current data, simulations and forecasts, DTs can greatly improve the decision-making, productivity and efficiency of several activities as well as reduce cost and time spent on on-site evaluations and assessments (QI et al., 2021).

Although DTs are still in modelling stage in the agriculture domain, they are mostly used in production, prognostics and health management (PHM) areas, providing more reliability, flexibility and predictability to their processes (TAO et al., 2019b). According to (RASHEED; SAN; KVAMSDAL, 2020), the eight values extension of DTs are: (1) Real-time remote monitoring and control, (2) Greater efficiency and safety, (3) Predictive maintenance and scheduling, (4) Scenario and risk assessment, (5) Better intra- and inter-team synergy and collaboration, (6) More efficient and informed decision support system, (7) Personalization of products and services and (8) Better documentation and communication. Furthermore, the main challenges for DT implementation are: ensuring interoperability, security, dependability, reliability and sustainability. Also included, is the successful implementation of the real-time two-way connection between the twins and the handling of the large data volume, data variety, connection latency and online processing of data (RASHEED; SAN; KVAMSDAL, 2020).

2.6 Cognitive Agriculture

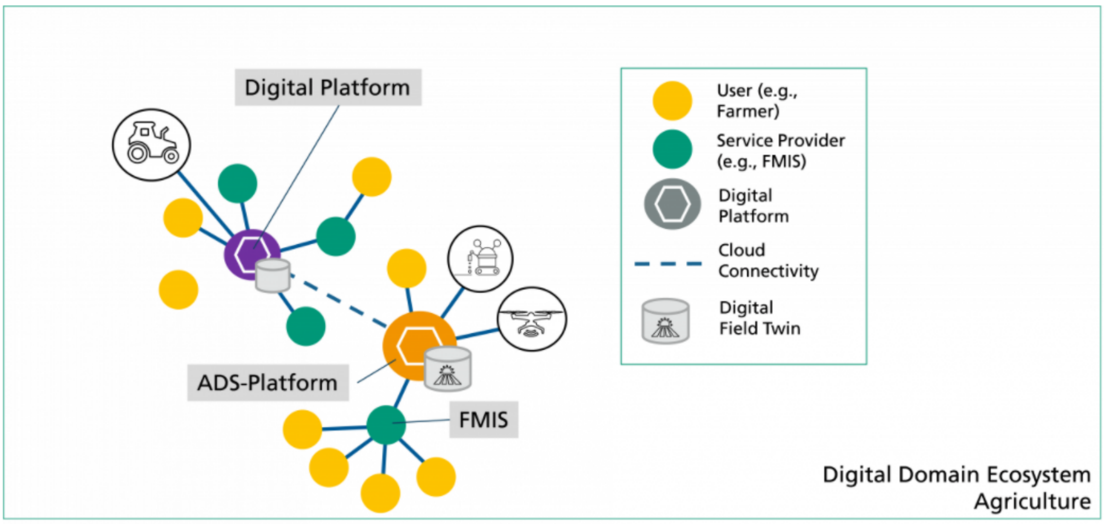
Cognitive Agriculture, short named COGNAC, is the lighthouse project from the Fraunhofer Society that comprises eight of its institutes in order to build a data-based agricultural ecosystem, Agricultural Data Space (ADS). The ADS aims to enable ways of connecting the numerous isolated digital ecosystems and making them usable as a whole for the farmer to achieve maximum productivity and sustainability on their farm (IESE, 2021c). Moreover, the ADS is envisioned to merge the existing digital ecosystems into a new one, as well as the entire agricultural value chain. As described by Fraunhofer, the ADS encompasses "farmers with their farms, machinery, and digital applications; service providers with agricultural or digital offers; manufacturers of agricultural machines or means of production with their own data platforms; as well as retailers and end customers" (IESE, 2021b). All these participants, in a working digital ecosystem, can share data among themselves and offer services based on this data. However, only a few data formats standards are set, and it is quite difficult to ensure that every domain element is covered by one. Therefore, it is proposed by the ADS to be able to translate the different formats as automatically as possible and interpret them to provide better interoperability between these systems (IESE, 2020). As any digital ecosystem, the ADS is enabled by a digital platform, the ADS Platform, to provide an interface between the participants of the ecosystem and implement their interactions according to set rules (IESE, 2020). The envisioned ADS is depicted in Figure 2.12. The figure demonstrate the ADS Platform as a digital platform that holds the DT and provides access to it to other platforms. This happens by the utilization of ontologies or format standards to interpret the data and provide a more interoperable interface between the platforms. The main functionalities of the ADS Platform, as detailed in IESE (2020), are:

- Central data storage: data stored and managed as DTs (this functionality is the focus of this work);
- Access to the management of access and usage rights: as part of data sovereignty the farmer should get an interface to manage who can access their data and how;
- Environment for services and algorithms: an operating environment for services or applications that can be used in the context of the platform;
- Data interface: an interface to provide data to services external from the platform;
- Data marketplace: a possibility to trade data with different levels of anonymization;

The project also researches the application of DTs in the agricultural domain for improvement in interoperability and data security, taking as reference its use in Industry 4.0 (IESE, 2021b). Initially, the project studies the creation of digital *Field Twins* as a field plays a major role in crop farming. The Field Twins should encapsulate all data belonging to a field that have great relevance, facilitating the services to find all necessary data for their execution in one place. For example, the Field Twin can provide data as the yields from the last four years, the current field boundaries and tracks, the soil moisture levels, harvesting prediction, and anything else stored from sensor data or other services (IESE, 2021b). The Field Twin has an API to be accessed inside the ecosystem. This means that a FMIS can use the Field Twin data without having to store it, therefore, a FMIS can even function without having any database and relying only on the ecosystem data stored in the Field Twin (IESE, 2021b). Moreover, the ADS Platform ensures data sovereignty for the farmers, so they can have all information and power needed to decide which entities can access their data and how. Furthermore, they will have the proper interface to change this decisions whenever wanted (IESE, 2020). The applications of DTs in agriculture are very large, but for this to happen, the DTs have to be designed to be flexible to endure the digital transformation process the domain is going through.

Moreover, several agriculture applications are being developed by each of the eight institutes to live in the ADS, connect to the Field Twins and gather data, share and analyze it, helping bring the ADS to life.

Figure 2.12 – ADS as envisioned by Fraunhofer



Source: (IESE, 2021b)

2.7 Related Works

Since the application of DTs in agriculture is still relatively new, it was somewhat challenging to find related works that comprise DT and BPM methods utilization for the improvement of interoperability in an agricultural operation with the development of a FMIS to test and prove it. However, the closest work found is by Zaninelli and Pace (2018) and is described below first, other relevant works are mentioned subsequently. A comparison between the related works and this work is shown in Table 2.1.

Zaninelli and Pace (2018) utilizes BPM and BPMN to model the milking processes of a small farm to organize its activities as workflows and drive the software development of a web-based FMIS for the traceability of milk called O3-Farm. BPMN was employed solely for the modelling of the O3-Farm processes, and the user interactions were further modelled with the UML language. As validation, they had 5 professional farmers test the old and the O3-Farm versions of a management system according to basic tasks and then responding a questionnaire with their opinion. The results show that the O3-Farm provides all needed data to trace milk yields as well as new features that improved usability, portability and efficiency. The new application also has the possibility of integration with other services due to its better distribution of agricultural data.

Keates (2019) examines the installment of BPM to the Internet of Things (IoT) implementations in cattle farming in Australia with the intent to achieve more value through improvement of decision support. They utilized the BPM Lifecycle defined by Dumas et al. (2018) and BPMN to model the processes specifically during the Process Redesign phase so that they could be later executed in a Business Process Management System (BPMS)(DUMAS et al., 2018). The authors concluded that it is very difficult to gather data from different systems and IoT solutions (lack of interoperability) and that this should be considered in the near future by these solutions providers, for the benefit of the customer. Furthermore, they conclude that the application of the BPM cycle helps all the stakeholders stay focused on their goals and ensure that a continuous improvement is kept.

Celestrini et al. (2019) proposes an IoT solution integrated with BPMN to manage the production process in Controlled Environment Agriculture. They developed an architecture using business process rules for managing the IoT devices through BPMN. Their work was validated by applying it to a case study to assist a vegetable production, with business rules modeled by a domain expert. The authors conclude that BPMN improves

Table 2.1 – Related Works Comparison

Characteristics/ Works	Zaninelli e Pace (2018)	Keates (2019)	Celestrini et. al (2019)	This Work
Applies DT concept		X*		X
Aims to better the interoperability between systems	X		X	X
Utilizes BPM	X	X	X	X
Integrates with IoT		X	X	
Develops a FMIS	X			X
Limitations	Improvement in interoperability depends on the standardization of agricultural data formats and greater integration between systems	No specific method of the BPM Lifecycle was used on each step and the Process Analysis step was missing * - DT concept was only mentioned as a solution for the application on the production chain in the future.		

the process modeling, thus providing more control of the production process and enhancing the decision-making of the producers. Moreover, BPMN enabled their architecture to become more flexible in the event of crop changes in the same environment without the need to change code.

2.8 Chapter Summary

In this chapter, the main concepts utilized in this work were defined and described in their state-of-the-art. They were BPM and its lifecycle, BPMN 2.0, focused on the elements used in this work, precision farming, FMISs, DT and the COGNAC project on which this work is based. Additionally, the related works were outlined.

3 SUGAR BEET FARMING PROCESS MODELLING

In this chapter, the whole process of sugar beet farming, from the decision to plant sugar beet to the point when the yields are sold to wholesalers, is discussed, modeled and evaluated with the participation of a domain expert from Fraunhofer IESE. The process of sugar beet farming is modeled according to the most common way it is currently executed in Germany for farmers that utilize digital tools without COGNAC's ADS Platform Field Twin integration. The generated model conforms to what was described by the domain expert in the process discovery method. Then it is verified, validated and analyzed to find and understand its disadvantages and vulnerabilities. From the analysis results, the to-be process is modeled regarding the analysis results and the integration with the ADS Platform Field Twin. Finally, it is also verified, validated and analyzed to recognize its improvements over the as-is process.

3.1 Process Discovery

The Process Discovery step was done in an Interview-Based approach with the agriculture domain expert from the Fraunhofer IESE. In total, there were three interviews in which the expert went through the sugar beet farming activities and answered questions done by the author throughout. The main questions asked were:

- Q1: Which information is needed by this activity?
- Q2: Which information is produced by this activity?
- Q3: Is this activity performed with the support of a system?
- Q4: Which kind of FMIS is needed for this activity?
- Q5: Where is the information needed by this activity stored?
- Q6: Where is the information produced by this activity stored?

After each interview, the process model was updated and then sent back to the expert along with its paraphrased text description. Meaning that, if the text is judged as correct by the expert, the model is also correct, therefore the model is considered semantically correct. The syntactic quality was assured by the BPMN modelling tool Signavio[1] from the company SAP, which was evaluated by Dias et al. (2019) to be the tool that provides the best support in process validations. Furthermore, the pragmatic quality

[1] https://www.signavio.com/

was assured by following the process modelling guidelines defined by Mendling, Reijers and Aalst (2008) and Avila and Thom (2019) mentioned in section 2.1.2. Moreover, the structural quality of the model was validated by two BPM experts from the UFRGS BPM research group. The result is an example farm that has three different systems to conduct its needed operations and represents how it would handle the sugar beet farming process.

To create precise process text descriptions from the model designed, a sentence template was used to translate the control flow information into text. The sentence template used was adapted by Silva et al. (2019). With this method, the model is completely paraphrased in text form while maintaining its semantic meaning. This enables the process analyst to validate it with the domain experts with fewer misunderstandings caused by the lack of understanding of the modelling language on their part. The sentence template is described in Table 3.1.

Table 3.1 – Sentence Template from Silva et al. (2019)

<table>
<tr><th>Element</th><th>Type</th><th>Sentence templates</th></tr>
<tr><td>Start</td><td>Sequence Split</td><td>The process starts when. . .
When the process starts, . . .</td></tr>
<tr><td>Sequence</td><td>Atomic 1
Atomic 2
Atomic 3
Aggregation</td><td>Next, . . .
Subsequently, . . .
After that, . . .
...<activity 1>and then <activity 2>.</td></tr>
<tr><td>End</td><td>Sequence
Join</td><td>Finally, the process ends.
..., the process ends.</td></tr>
<tr><td>Exclusive Choice</td><td>Split
Join</td><td>..., one of the <number>alternative procedures is executed.
In any case, . . .</td></tr>
<tr><td>Inclusive Choice</td><td>Split
Join</td><td>..., <number>alternative procedures may be executed.
Afterwards, . . .</td></tr>
<tr><td>Choice Paths</td><td>Ordinal
Conditional</td><td>In the <first | second | third. . .>procedure, . . .
If <cond.>, ...</td></tr>
<tr><td>Parallelism</td><td>Split
Join
Path 1
Path 2</td><td>..., <number>procedures are executed in an arbitrary order.
After each case, . . .
In the meantime, . . .
At the same time, . . .</td></tr>
<tr><td>Skip</td><td>Split
Join</td><td>If required, . . .
In any case, . . .</td></tr>
<tr><td>Loop</td><td>Join 1
Join 2</td><td>If required, <role>repeats the latter steps and continues with. . .
Once the loop is finished . . .</td></tr>
</table>

Here is the text description extracted, followed by the final as-is model version. "The *Sugar Beet Farming As-Is* process starts when the farmer decides to plant sugar beet in the field (*Start Event: Decision to Plant Beet Made*). Next, the farmer checks if the *Field Geo-Data* is up-to-date in *FMIS 1* (*Task: Check Field Geo-Data in FMIS 1*). The system *Field Geo-Data* can either be up-to-date or out-of-date according to the field geometry desired for the current sugar beet farming. If the *FMIS 1 Field Geo-Data* is out-of-date, the farmer then updates it in *FMIS 1* which stores the *Field Geo-Data (Format 1) [Updated]* in its database and after it, they can move on to the planning of the sugar beet seeding (*Task: Update FMIS 1 Field Geo-Data*). If the *FMIS 1 Field Geo-Data* is up-to-date, the farm can go directly to the planning of the sugar beet seeding.

Subsequently, the farmer plans the seeding operation with the support of a FMIS with seeding features (*FMIS 1*) that contains his field's geographic data in a format chosen by *FMIS 1* (*Field Geo-Data (Format 1)*) in its database and results in a target application map (*Seed Application Map (Target)*) for the sugar beet seeds that is also stored in *FMIS 1* database (*Task: Plan Beet Seeding*). After that, the farmer contracts a contractor (*Contractor 1*) of his choice to perform the seeding, which will notify the farmer when the job is done (*Task: Contract Seeding from Contractor 1*). When the farmer receives the notification with the invoice for the work done and the actual seed application map (*Seed Application Map (Actual)* (*Intermediate Catching Message Event: Seeding Work Invoice Received*), then they can pay *Contractor 1* for the work done (*Task: Pay Contractor 1 for Beet Seeding*).

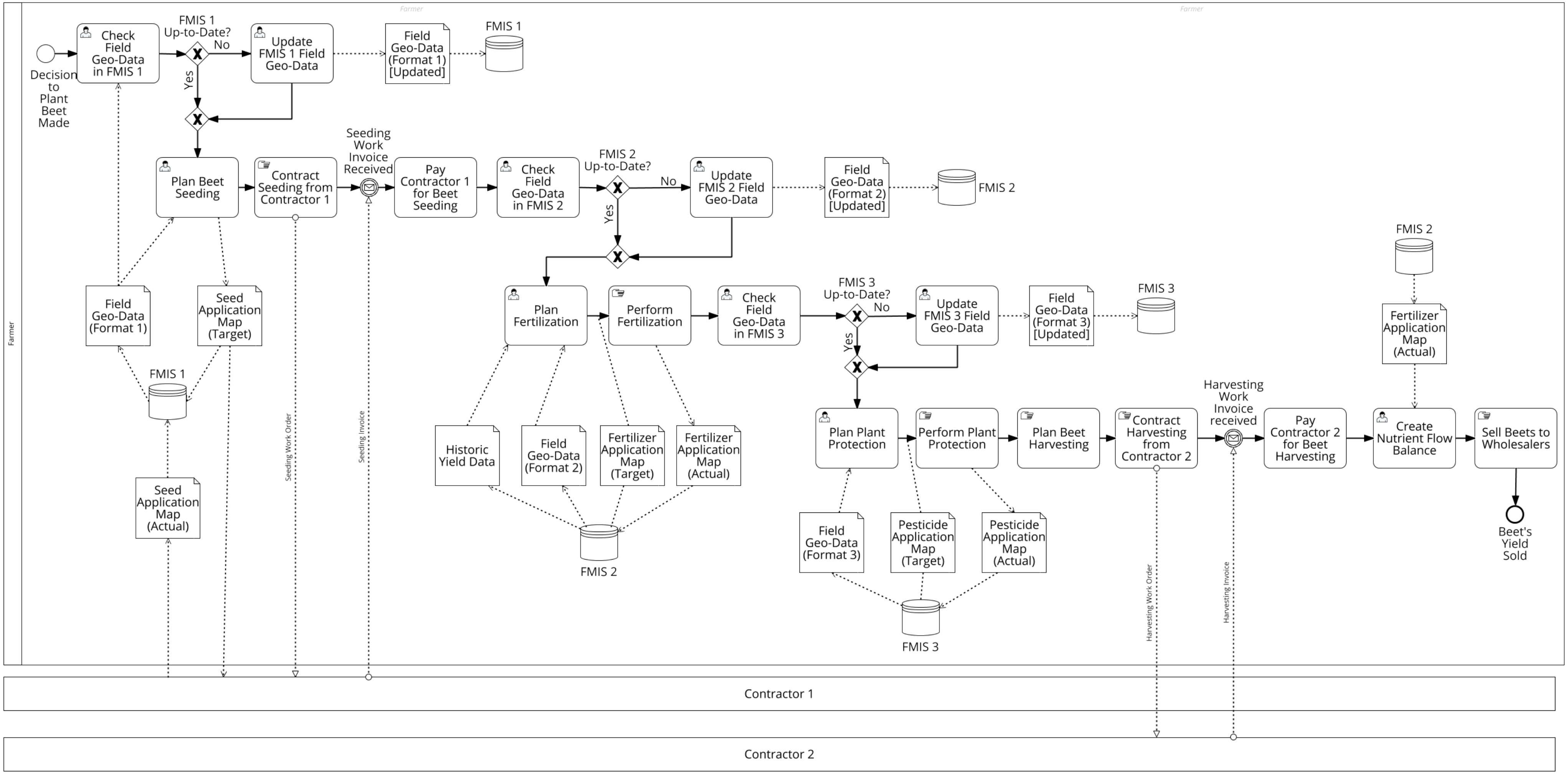
Afterwards, the farmer checks if the *Field Geo-Data* is up-to-date in *FMIS 2* (*Task: Check Field Geo-Data in FMIS 2*). If the *FMIS 2 Field Geo-Data* is out-of-date, the farmer then updates it in *FMIS 2* which stores the *Field Geo-Data (Format 1) [Updated]* in its database, and after it, they can move on to the planning of the sugar beet fertilization (*Task: Update FMIS 2 Field Geo-Data*). If the *FMIS 2 Field Geo-Data* is up-to-date, the farmer can go directly to the planning of the sugar beet fertilization. Next, the farmer plans the fertilization of his field with the support of a FMIS (*FMIS 2*) with fertilization features that also contains the farmer's field geographic data, in a format chosen by *FMIS 2* (*Field Geo-Data (Format 2)*), and *Historic Yield Data* in its database and this task results in a *Fertilizer Application Map (Target)* that is also stored in *FMIS 2* database (*Task: Plan Fertilization*). Subsequently, the farmer performs the fertilization manually based on the *Fertilizer Application Map (Target)*, that results in a *Fertilizer Application Map (Actual)* stored in *FMIS 2* (*Task: Perform Fertilization*).

Next, the farmer checks if the *Field Geo-Data* is up-to-date in *FMIS 3* (*Task: Check Field Geo-Data in FMIS 3*). If the *FMIS 3 Field Geo-Data* is out-of-date, the farmer then updates it in *FMIS 3*, which stores the *Field Geo-Data (Format 1) [Updated]* in its database, and after it, they can move on to the planning of the sugar beet weed control (*Task: Update FMIS 3 Field Geo-Data*). If the *FMIS 3 Field Geo-Data* is up-to-date, the farmer can go directly to the planning of the sugar beet weed control. After that, the farmer plans the weed control of his field with the assistance of a FMIS (*FMIS 3*) with weed control features that also contains the farmer's field geographic data*Field Geo-Data (Format 3)* format chosen by *FMIS 3* stored in its database, and this task results in a *Pesticide Application Map (Target)* that is also stored in *FMIS 3* database (*Task: Plan Weed Control*). Then, the farmer performs the weed control manually based on the *Pesticide Application Map (Target)*, that results in a *Pesticide Application Map (Actual)* that is also stored in *FMIS 3* (*Task: Perform Weed Control*).

Subsequently, the farmer plans the harvesting of his field manually (*Task: Plan Beet Harvesting*). Then, the farmer contracts a contractor (*Contractor 2*) for the harvesting work, which will notify the farmer when the job is done (*Task: Contract Harvesting from Contractor 2*). When the farmer receives the notification with the invoice for the work done and the *Harvest Yield Map*, which is stored in *FMIS 2*, then they can pay *Contractor 2* for the work (*Task: Pay Contractor 2 for Beet Harvesting*).

Then, the farmer creates the nutrient flow balance with the aid of a FMIS (*FMIS 2*) with *Fertilizer Application Map (Actual)* as input (*Task: Create Nutrient Flow Balance*). Next, the farmer sells the sugar beets to wholesalers based on *Harvest Yield Map* (*Task: Sell Beets to wholesalers*). The process ends when the beets are sold (*End Event: Beets Yield Sold*)."

Figure 3.1 – Sugar Beet Farming As-Is



Source: The Author

3.2 Process Analysis

With the *as-is* model ready, the process analysis step can start. As defined in section 2.1.1, this step can be subdivided into *qualitative* and *quantitative* techniques. For this work, the qualitative approach was chosen due to its independence of the activities measurements of, for example, time and cost which are very specific to each farm and thus hard to specify. The technique selected for this step is the *Waste Analysis*, which aims at finding wasteful activities in a process from the view of the client.

By inspecting the as-is model, the activities that represent possible wastes are the *Check Field Geo-Data in FMIS ** and their subsequent *Update FMIS * Field Geo-Data* as they deal essentially with the same data, but in different systems. In reality, after having decided to plant sugar beets in a field, the farmer checks if the current stored field geographic data is the same as the one determined in the field rotation planning. A field's geographic data, most importantly the boundaries, can be changed if the farmer decides to merge some fields into one or to divide a field into smaller ones depending on the farmer's needs. According to the domain expert consulted, this change is only done once before a new season. Therefore, it makes sense to perform this check only once and at the beginning of the process, before the seeding planning. Then, the other tasks can be considered *overprocessing* waste in the farmer's point of view.

Another issue with this process is that each FMIS used by the farmer has its own database and do not share any data between each other, meaning the data is distributed. Furthermore, these FMISs demand some of the same data information about the farmer's field, in this case the field geographic data, meaning this data is replicated and, thus, prone to future data inconsistencies affecting the process quality. Therefore, to ensure that the process can return its best value, that is a good yield, the farmer needs to give extra effort to keeping these FMISs consistent with the same updated data, which takes time and affects the process efficiency. Assuming all these tasks take the same amount of time x for checking and updating the system, regardless of the FMIS being checked or updated, it means the farmer takes 3 times the actual needed duration ($3x$) to ensure the data consistency throughout the process.

Furthermore, each of these FMISs use a different format to represent the field's geographic data, as there was no set standard, thus, compromising even more the interoperability possibilities between them. These issues are documented in the Issue Register Table 3.2.

Table 3.2 – Issue Register of Sugar Beet Planting As-Is Process

Issue 1: Overprocessing of Field Geo-Data Description: Farmers need to perform the same tasks up to three times during a process to ensure data consistency Data and assumptions: A farm has up to three independent FMISs to cover specific process activities checking and updating each at least once during a process represents up to three times actually needed time duration for these tasks Qualitative impact: This overprocessing creates frustration to the farmer and affects the process efficiency Quantitative impact: Not applicable
Issue 2: Data Distribution Description: Data is distributed across FMISs and other farm systems that do not share data with each other. Data and assumptions: Farm systems have at least one data in common, e.g. field geo-data, each with its own copy. Qualitative impact: This increases the probability of data inconsistencies between the systems throughout the process Quantitative impact: Not applicable
Issue 3: Data Interoperability Description: There is no common data format standard between the farm systems. Data and assumptions: Common data formats are Shapefiles, GeoJSON and GeoTIFF Qualitative impact: This compromises the interoperability between the systems and prevents the farmer of being able to manually share data easily from one system to another. Quantitative impact: Not applicable

This analysis goes in accordance with the issues already brought to the farming industry's attention by the farmers. The domain expert also pointed that the farmers find themselves having to maintain 2 to 3 FMISs in order to have all their processes activities covered. Due to the large size of the agriculture domain, having specialized FMISs is not the issue per se, but their lack of interest in sharing data with each other is ((EIP-AGRI), 2015). They do not see the benefit for them as it is a very costly development operation to change their systems and databases to be compatible with each other and the farmer still pays for their service as they do not have a better option.

3.3 Process Redesign

This work uses the Redesign Orbit presented in Figure 2.2 to filter down which redesign methods would fit best to this case. Considering that this work takes as a basis the current sugar beet business process previously discovered and analyzed to be redesigned, the redesign methods of the transactional nature are best suited for this case. Moreover, since the process is based on the farmer's perspective, the method should be also outward-looking. Finally, an analytical approach should be taken, as it is better to verify and validate, since it involves statistics of the process to analyze its characteristics (DUMAS et al., 2018). This analysis filtered the redesign methods down to three options: *Benchmarking, ERP-driven Redesign* and *Lean*. This work utilizes the Lean method, because it focuses on the added-value of each activity, while the others comprise mainly standard processes for enterprises (DUMAS et al., 2018). The Lean method also developed by the Toyota Production System and popularized by Womack, Jones and Roos (1990). In accordance with the Waste Analysis method used in this work, the Lean technique aims at waste elimination in a process, by assessing if an activity generates value from the perspective of a customer.

Alongside the redesign methodology chosen, there are several redesign heuristics that can be used to support the redesign process. Reijers and Mansar (2005) did an overview and qualitative evaluation of the most successful heuristics in order to define best practices in business process redesign. Based on the analysis results, the *Integral Technology* heuristic can be used to solve the *Issue 2: Data Distribution*, since it relies mostly on the databases utilized by the FMISs. This practice is technology oriented and implies the application of new technology to elevate physical constraints in a process, thus achieving some kind of advantage as better quality of service or less time spent on tasks (REIJERS; MANSAR, 2005). This would be done through the integration of the Digital Field Twin in the ADS Platform to be accessed by the different agricultural systems utilized by the farmer.

With the Field Twin, *Issue 3: Data Interoperability* would also be resolved as the ADS Platform is envisioned to enforce data standards or, in their absence, interpret the different data formats in order to provide better interoperability to the systems in the ecosystem. Furthermore, with the data being centralized in the field twin, *Issue 1: Field Geo-Data Overprocessing* is solved, because the need to check the field geo-data more than once in a sugar beet process ceases. *Task elimination* is the redesign heuristic that makes most sense in this case, as a task is considered unnecessary when it adds no value from the customer's point of view (REIJERS; MANSAR, 2005). *Task redundancy* is defined as a special case of task elimination, which fits exactly to the sugar beet use case studied in this work. This heuristic is focused on business process operation, e.g. how the workflow is implemented, which seeks to improve the process speed and reduce its cost, sometimes with the consequence of reducing the process quality, but in this case, the Field Twin ensures data consistency, which is the main concern identified for the sugar beet field geo-data quality.

Based on the issues found by the analysis step of the BPM lifecycle and on the solutions researched by the COGNAC project, the as-is process was redesigned to show the integration of the ADS Platform and the Field Twin as data source for the FMISs and other systems and services that the farmer may want to utilize in their farm. The to-be model structural quality was validated by two BPM experts from UFRGS. Moreover, the semantic quality was validated by a COGNAC expert from Fraunhofer, who assured the model fits to the COGNAC vision. Finally, the pragmatic quality was assured by also following the process modelling guidelines. The final version of the to-be business process model created along with its paraphrased version are shown below.

"The *Sugar Beet Farming To-Be* (Figure 3.2) process starts when the farmer decides to plant sugar beet in the field (*Start Event: Decision to Plant Beet Made*). Next, the farmer checks if the *Field Geo-Data* is up-to-date in the *Field Twin* through a FMIS of his choice (*Task: Check Field Geo-Data*). The Field Geo-Data can either be up-to-date or out-of-date in the *Field Twin* according to the field geometry desired for the current sugar beet farming. If the *Field Geo-Data* is out-of-date, the farmer then updates it in any FMIS of his choice, which stores it in the *Field Twin*, and after it, they can move on to the planning of the sugar beet seeding (*Task: Update Field Twin Geo-Data*). If the *Field Geo-Data* is up-to-date, the farmer can go directly to the planning of the sugar beet seeding.

Subsequently, the farmer plans the seeding operation with the support of a FMIS with seeding features that accesses his field's geographic data (*Field Geo-Data*) from the *Field Twin* and results in a target application map (*Seed Application Map (Target)*) for the sugar beet seeds that is also stored in the *Field Twin* (*Task: Plan Beet Seeding*). Then, the farmer contracts a contractor (*Contractor 1*) of his choice to perform the seeding, which will notify the farmer when the job is done (*Task: Contract Seeding from Contractor 1*). When the farmer receives the notification with the invoice for the work done and the actual seed application map (*Seed Application Map (Actual)* (*Intermediate Catching Message Event: Seeding Work Invoice Received*), then they can pay *Contractor 1* for the work (*Task: Pay Contractor 1 for Beet Seeding*).

Next, the farmer plans the fertilization of his field with the support of a FMIS, that has fertilization specific features, which accesses the farmer's *Field Geo-Data* and *Historic Yield Data* from the *Field Twin*, and results in a *Fertilizer Application Map (Target)* (*Task: Plan Fertilization*). Subsequently, the farmer performs the fertilization manually based on the *Fertilizer Application Map (Target)*, that results in a *Fertilizer Application*

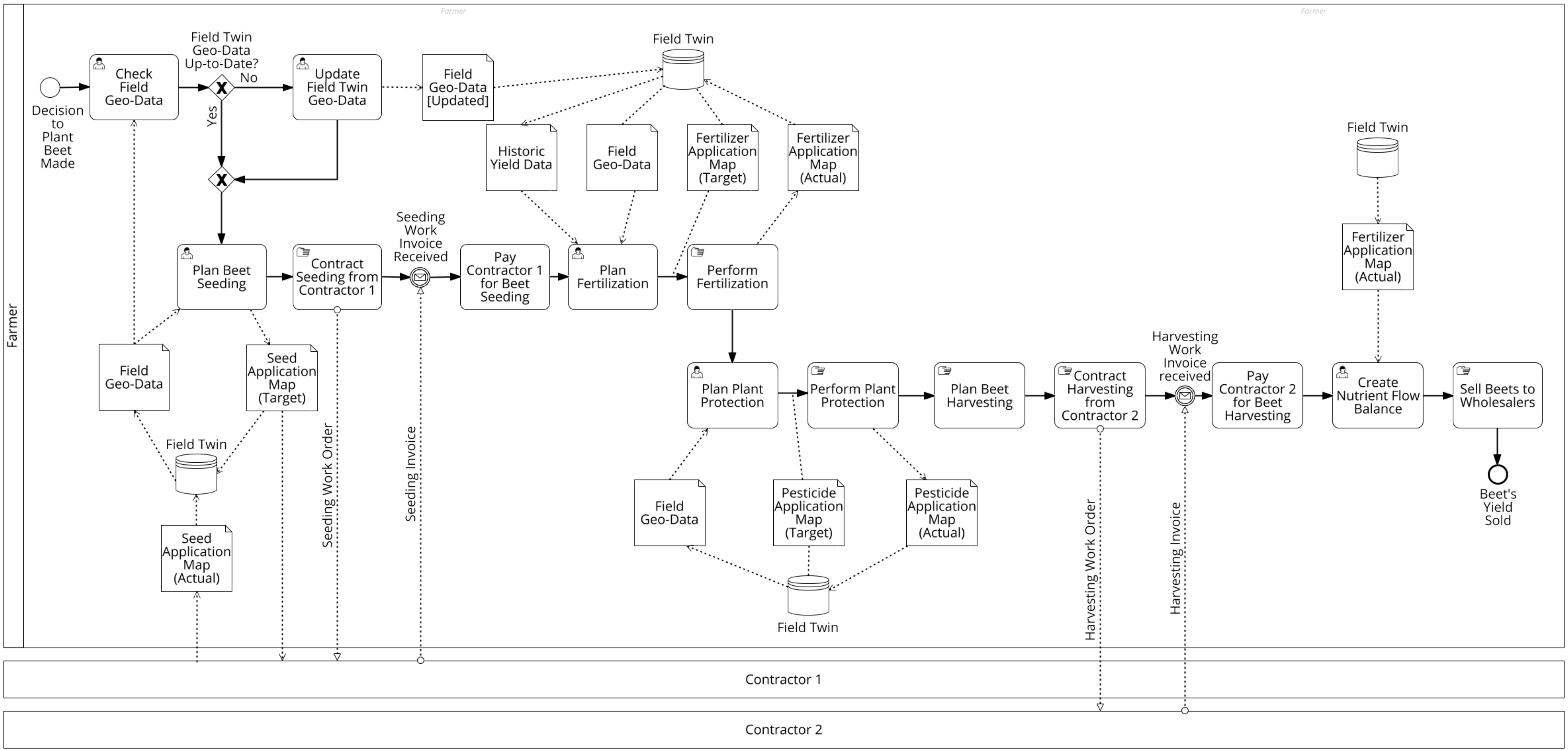
Map (Actual) stored in the *Field Twin* (*Task: Perform Fertilization*).

Afterwards, the farmer plans the weed control of his field with the assistance of a FMIS that has specific weed control features and also accesses the farmer's *Field Geo-Data* from the *Field Twin* and results in a *Pesticide Application Map (Target)* that is stored in the *Field Twin* (*Task: Plan Weed Control*). Then, the farmer performs the weed control manually based on the *Pesticide Application Map (Target)*, that results in a *Pesticide Application Map (Actual)* which is stored in the *Field Twin* (*Task: Perform Weed Control*).

Subsequently, the farmer plans the harvesting of his field manually (*Task: Plan Beet Harvesting*). Then, the farmer contracts a contractor (*Contractor 2*) for the harvesting work, which will notify the farmer when the job is done (*Task: Contract Harvesting from Contractor 2*). When the farmer receives the notification with the invoice for the work done and the *Harvest Yield Map*, which is stored in *FMIS 2*, then they can pay *Contractor 2* for the work (*Task: Pay Contractor 2 for Beet Harvesting*).

Then, the farmer creates the nutrient flow balance with the assistance of a FMIS with the *Fertilizer Application Map (Actual)* as input (*Task: Create Nutrient Flow Balance*). Next, the farmer can sell the sugar beets to wholesalers based on *Harvest Yield Map* (*Task: Sell Beets to wholesalers*). Finally, the process ends when the beets are sold (*End Event: Beets Yield Sold*)."

Figure 3.2 – Sugar Beet Farming To-Be (With integration of the ADS Platform)



Source: The Author

3.4 Chapter Summary

In this chapter, the sugar beet farming process from start to finish was discussed accordingly with an interview-based discovery method with a Fraunhofer domain expert. Then, its as-is model was created in BPMN following the process modelling guidelines for pragmatic quality, verified by the Signavio tool and two BPM experts from UFRGS for syntactic quality assurance and paraphrased to text format for validation with the domain expert to ensure semantic quality. In sequence, the model was analyzed based on the Waste Analysis method by Toyota Production System to find that the process has issues based on data distribution that increased the occurrence probability of data inconsistency, data interoperability and overprocessing of this data as a consequence of the previous two. In the redesign step, the process was enhanced according to the Lean methodology, also by Toyota, to solve these issues. Based on the redesign decisions and the integration of the ADS Platform researched by the COGNAC project, the to-be model was created also in BPMN. Finally, the process structural quality was validated by two BPM experts from UFRGS, semantically validated by a COGNAC expert and its pragmatic quality was assured by the process modelling guidelines from Mendling, Reijers and Aalst (2008) and Avila and Thom (2019).

4 FMIS PROTOTYPE

This chapter presents that, in contribution to the COGNAC project, a FMIS prototype was developed by the author to be the first third-party service to connect to the ADS Platform and the Field Twin, thus cooperating with the demonstration and validation of the usability of the platform from its early stages. The prototype also is the first service with a UI developed for the project. Moreover, when completed, this FMIS can be used in the to-be process previously modeled to be validated and also further contribute to the ADS validation. The motivation behind the implementation of a new FMIS is to make a web application fully compatible with the ADS Platform to be made available as an open-source system in the near future, and to add new features for connecting with other COGNAC services as necessary. At the time of this work's publication, unfortunately, it is not yet released as open-source, therefore the code to this prototype can not yet be shared.

Initially, the design decisions of the prototype are presented, defining the system's architecture and the technologies chosen for the development along with the rationale of the decision. In sequence, the functionalities of the system are detailed, defining the use cases and how they work. Lastly, the functioning prototype is demonstrated.

4.1 Design Decisions

Design decisions play a big role in the development of any system, they are present from the architecture design to any new modification a system may go through. The reuse of any software architecture, means the reuse of the design decisions made that were already applied and tested (JANSEN; BOSCH, 2005).

4.1.1 Architecture

As a third-party service to connect to the ADS Platform, Basic FMIS was designed to have a web application architecture. According to Nikkilae, Seilonen and Koskinen (2010), this architecture seems to be the most well-suited for an FMIS that supports precision farming, as any device that can connect to the internet and is equipped with a web browser can connect to the system and visualize the most recent information.

Therefore, the FMIS can be accessed from, for example, the field where there is internet connection while the farmer makes visual observations. Furthermore, it can provide, if well-designed, a highly usable user interface similar to the ones in an on-premise FMIS. Another advantage of the web architecture is that the data storage is not on-site and, thus, can be considered more secure (NIKKILAE; SEILONEN; KOSKINEN, 2010). Essential data back-ups and system updates are no longer a concern for the farmer. The off-site data storage can be criticized for its privacy issues, however the ADS will tackle all aspects regarding it.

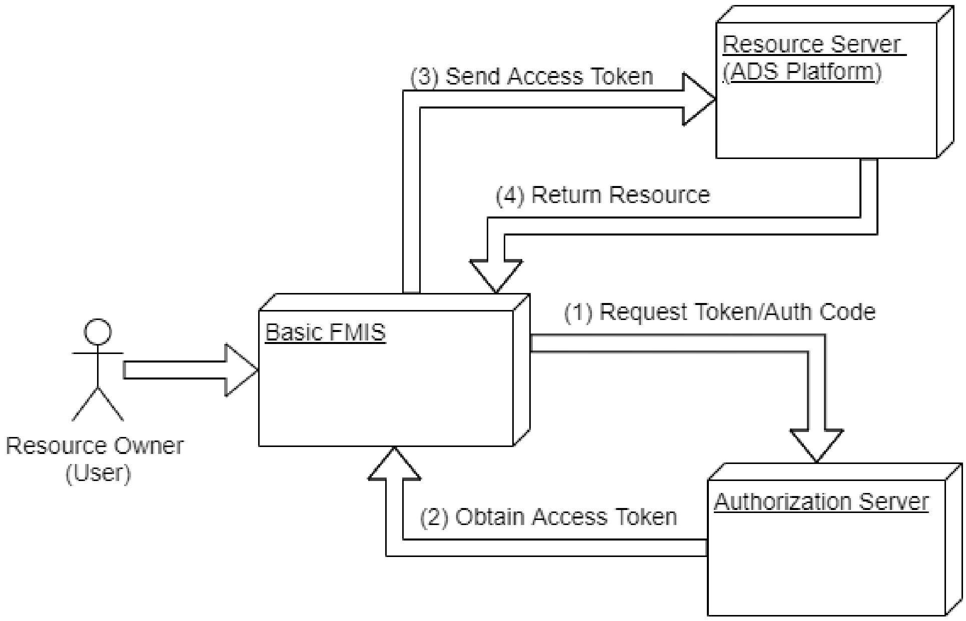
The communication layer of the Basic FMIS is designed to use the HTTP protocol along with OAuth2.0 [1] authorization protocol to connect to the ADS Platform API. The Authorization Code Flow is the standard used to provide the client, Basic FMIS, with a token to act on behalf of the user, the farmer. First, (1) at each login, the Basic FMIS requests an access token from the ADS Platform authorization server which requests the user their login credentials. Then, if the credentials were valid, (2) Basic FMIS gets the token in the response from the authorization server, stores it on its local session storage and (3) adds it in the authorization header on each request to the API, and, if the token is not yet expired, (4) the API returns the requested resource. This flow is depicted in Figure 4.1. The data exchange format used is JSON, which is widely used. Based on that and on its great acceptance in the Digital Farming domain, the GeoJSON format for encoding geographical structured data was chosen as the standard for Basic FMIS. Finally, Basic FMIS does not have a database as it is not necessary for its functions so far since the DT from ADS Platform can provide all relevant and latest data from a registered field.

4.1.2 Technologies

Considering the objective was to develop a web FMIS, it was decided to use the *JavaScript*[2] language. JavaScript is a language that runs on the client side of the web, being used to give life to the web pages by designing and programming how they should behave given an event. Furthermore, JavaScript is supported by the vast majority of the browsers, reducing portability issues. To enhance the application with more complex visual features, *React*[3] and *Angular*[4] were taken into consideration. A brief research on both

[1] https://oauth.net/2/
[2] https://developer.mozilla.org/en-US/docs/Web/JavaScript
[3] https://reactjs.org/
[4] https://angular.io/

Figure 4.1 – Basic FMIS - Authorization Flow



Source: The Author

was made, resulting in Table 4.1. Based on React's better support for lightweight applications, faster development and uncomplicated scaling, in case Basic FMIS is chosen to become a full FMIS, React was defined as the front-end library. React is component-based and enables building modular and reusable user interfaces specifically for Single-Page Applications, web applications that can change their display or perform a user interaction without having to completely reload the page. This decision was made also due to the fact that the author is already experienced with these technologies, and the project prioritized having a small learning curve to fulfill this development.

The project was created with *Create React App*[5], which prepares the whole development environment with the latest JavaScript features and optimizes the application for production. Next, both *React-Boostrap*[6] framework and *Node-Sass*[7] libraries were chosen to extend the interface design possibilities. As a key feature of a crop farm specific FMIS is the map overview of fields, the FMIS prototype was also envisioned to display and manage field information on a map. For this purpose, the *Leaflet*[8] open-source library was chosen, as it is a simple, yet efficient library that can be extended with various plugins if needed. Moreover, to provide drawing and editing features to manage the field

[5]https://reactjs.org/docs/create-a-new-react-app.html
[6]https://react-bootstrap.github.io/
[7]https://github.com/sass/node-sass
[8]https://leafletjs.com/

Table 4.1 – Considered Libraries Pros and Cons

Technologies	Pros	Cons	Remarks
React	Better for apps that need more recurrent updates; A smaller learning curve, faster development; Better for modern web development and light-weight applications (SPA and mobile apps); Straightforward scaling; Bigger support;	React is constantly being updated; Relies on other libraries for development (tradeoff for flexibility);	Single-direction data flow (more control over the project); Virtual DOM
Angular	Best suited for large scale feature-rich applications; A more complete framework, full of features from templates to testing; The best option for Native, hybrid and web apps; Clear best practices;	Can decrease performance for heavy applications; Bigger learning curve; More difficult to deploy; TypeScript;	Two-Way binding (considered an antipattern); Real DOM

boundaries in the leaflet map, the *Geoman-oi/leaflet-geoman*[9] plugin was added.

Furthermore, to set up the HTTP connection to the ADS Platform API, the *Axios*[10] library is used. Moreover, to handle the authentication OAuth2.0 protocol used by the ADS Platform, the *oidc-client*[11] library was chosen as it is a simple identity layer on top of the OAuth2.0 Protocol, that allows clients to verify the identity of the user. Next, to keep the user logged status saved in the app state, the *Redux*[12] library is used. Finally, to create the test environment with branch coverage of at least 80% and handle unit tests for react components, *Jest*[13] framework and *Enzyme*[14] library were chosen. A table with the main frameworks and libraries used in the prototype mentioned here is presented in Table 4.2.

4.2 Functionalities

Basic FMIS was envisioned mainly to view a part of the Field Twin data and to provide a friendlier user interface to manage it. This includes connecting to the ADS Platform with the farmer's login information. At the first time the farmer logs in with his ADS account, the application requests the farmer's authorization to access and manage their field twin data through the authorization server. After logged in, there are several activities that can be performed on the DT through the Basic FMIS. These use cases are described below and depicted in the use case diagram in Figure 4.2. Moreover, the

[9] https://github.com/geoman-io/leaflet-geoman
[10] https://axios-http.com/
[11] https://github.com/IdentityModel/oidc-client-js
[12] https://redux.js.org/
[13] https://jestjs.io/
[14] https://enzymejs.github.io/enzyme/

Table 4.2 – Basic FMIS Main Frameworks and libraries

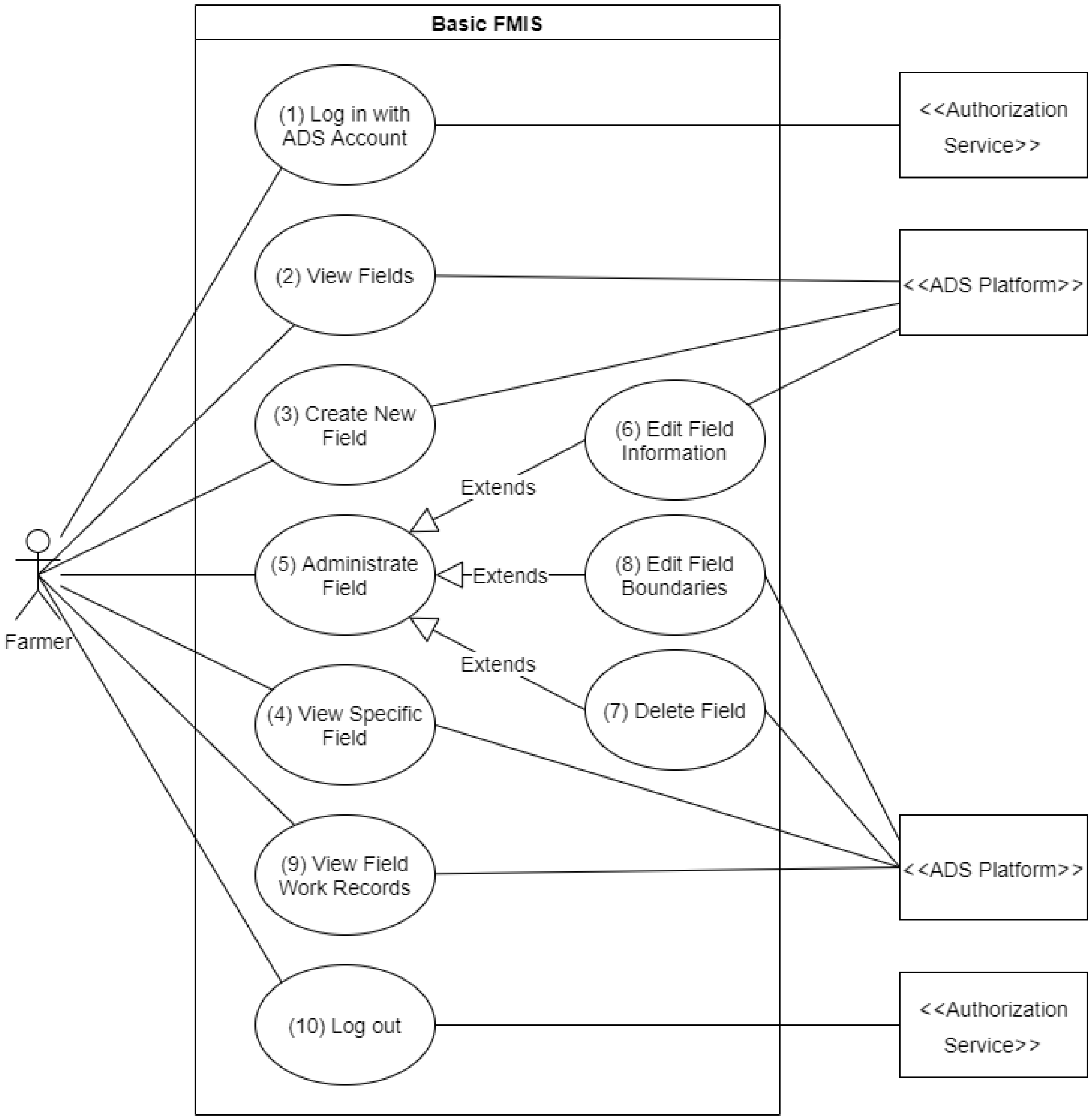
Name	*Description*
React	Library for the user interface.
React-Bootstrap	Front-End framework for complementing React with pre-built components and themes.
Node-Sass	Library for integrating Sass preprocessor for extending CSS capabilities.
Leaflet	Library for interactive maps.
Axios	Promise based HTTP client for the browser and node.js.
Oidc-client	Provides protocol for OIDC and OAuth2 with management methods.
Redux	Library that provides a predictable state container for JavaScript applications.
Geoman-io/leaflet-geoman	Leaflet plugin for drawing and editing geometry layers
Jest	Testing framework, highly recommended by React.
Enzyme	Testing library to facilitate testing react components along with enzyme-adapter-react-16.

Source: The Author

sequence diagram in Figure 4.3 shows in more detail how Basic FMIS interacts with the external systems.

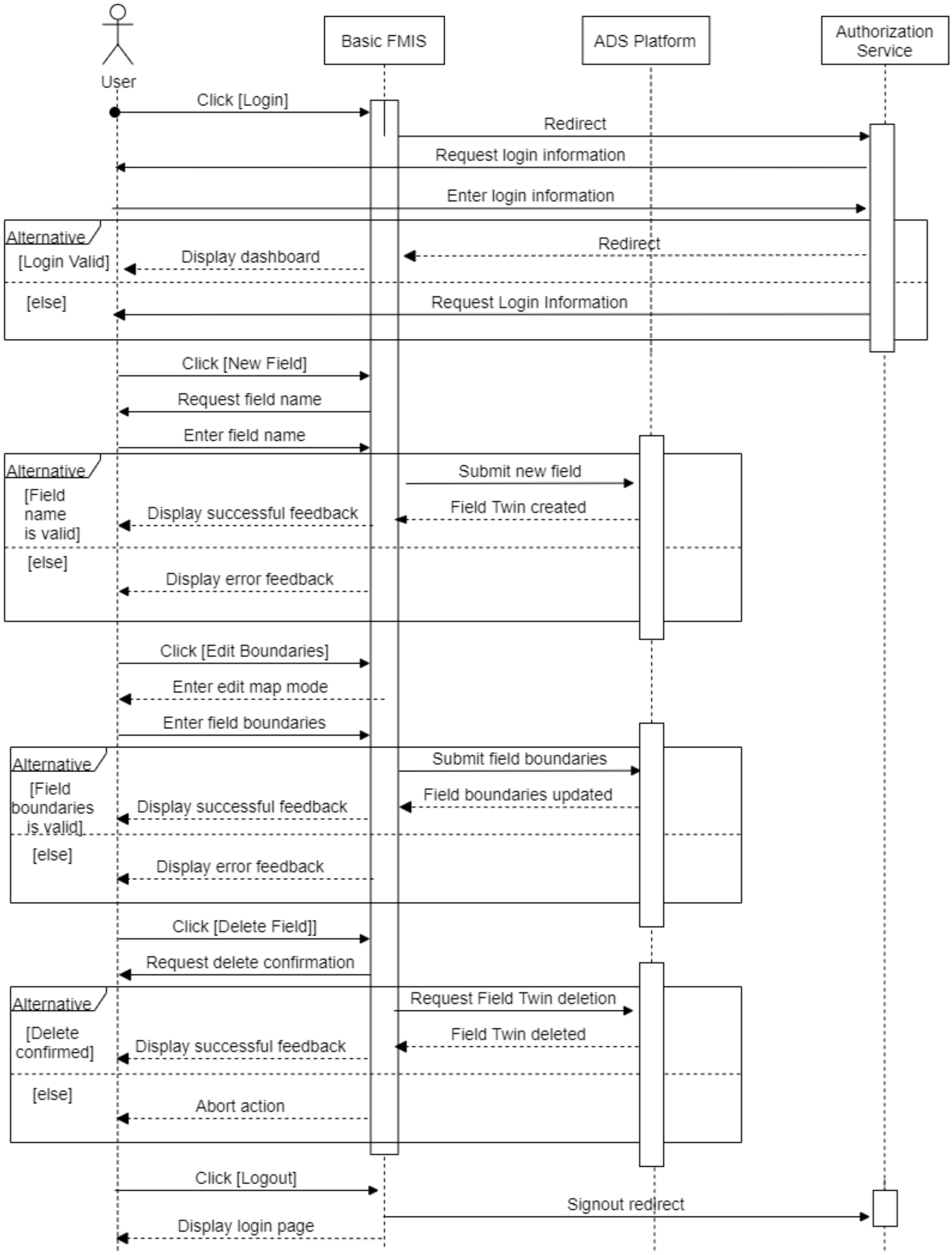
As soon as the farmer has an ADS Platform account, they can (1) log in to their account. After logged in, they can (2) view the fields they have already created, either in a dashboard or in a list style, both with a map displaying all the fields with their boundaries. The farmer can also (3) create a new field twin. With a field already registered in the ADS Platform, it means a DT of the field was created and through the Basic FMIS the farmer can (4) view this specific field information and (5) administrate it. The administration features three other use cases: (6) editing the field's basic information, which, at the time of this publication, is only its name; (7) deleting the field's DT; and (8) editing the field's boundaries. The editing of the field's boundaries involves using the interactive map to draw the polygon that defines the field's boundaries. Furthermore, the farmer can (9) view the work records of the four types of jobs performed in the field, they are: Application, Fertilization, Weed Control and Harvesting. These work records can be uploaded to the DT through the ADS Platform API by other services authorized by the farmer, the ones shown in the demonstration example in the next section were uploaded by another project inside COGNAC. Finally, the farmer can (10) log out of the Basic FMIS.

Figure 4.2 – Basic FMIS Use Case Diagram



Source: The Author

Figure 4.3 – Basic FMIS Sequence Diagram

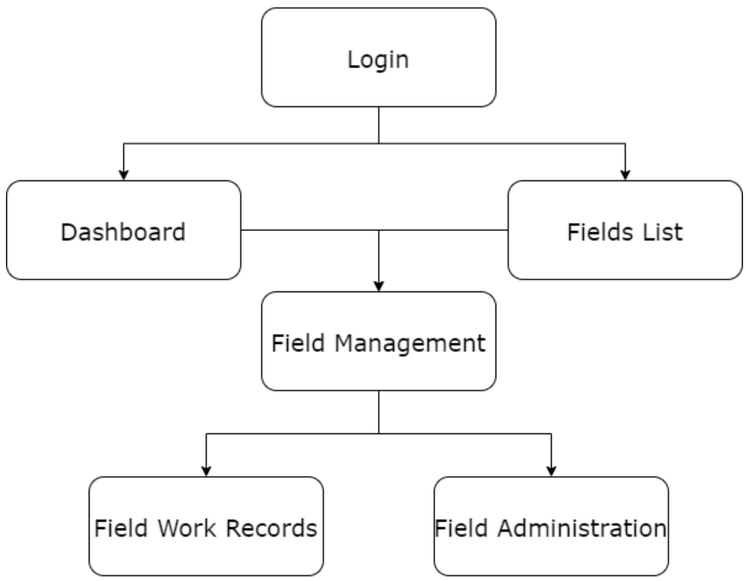


Source: The Author

4.3 Demonstration

This section presents a collection of features developed in the prototype based on the technologies and functionalities described beforehand. Based on the use cases presented in the previous section, the site navigation is defined as shown in the site map in Figure 4.4.

Figure 4.4 – Basic FMIS Site Map

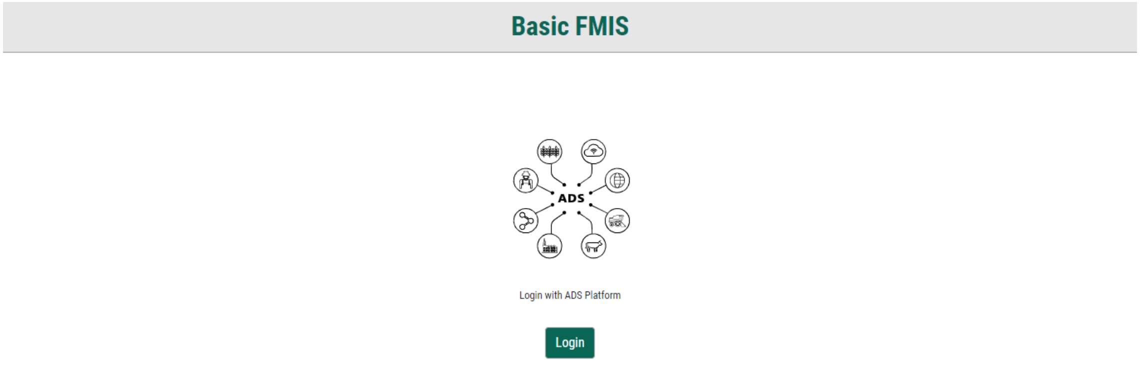


Source: The Author

The Basic FMIS initial state is shown in Figure 4.5, which is the *Login Page*. When the user clicks on the *Login* button, the application redirects to the ADS Platform authentication service, where the user can enter their login information. Upon positive response from the authentication service, it redirects back to the Basic FMIS which gets the user through the oidc-client UserManager event and saves it to the application state. When the application state changes, all components that listen to the state property changed, update accordingly. Therefore, the pages protected by a private route component that listened to the state, are accessible, and the user can navigate until they log out.

Then, the home page of the Basic FMIS becomes the *Dashboard*, as shown in Figure 4.6. In the Dashboard, there is a general visualization of all fields owned by the logged farmer in an interactive map, surrounded by placeholders of new features that may come in the future. From this page, the user can click directly on a field on the map to manage it, or they can navigate to the *Fields List Page* through the tab menu in the top left corner to visualize all fields in a list along with the map or to create a new field by

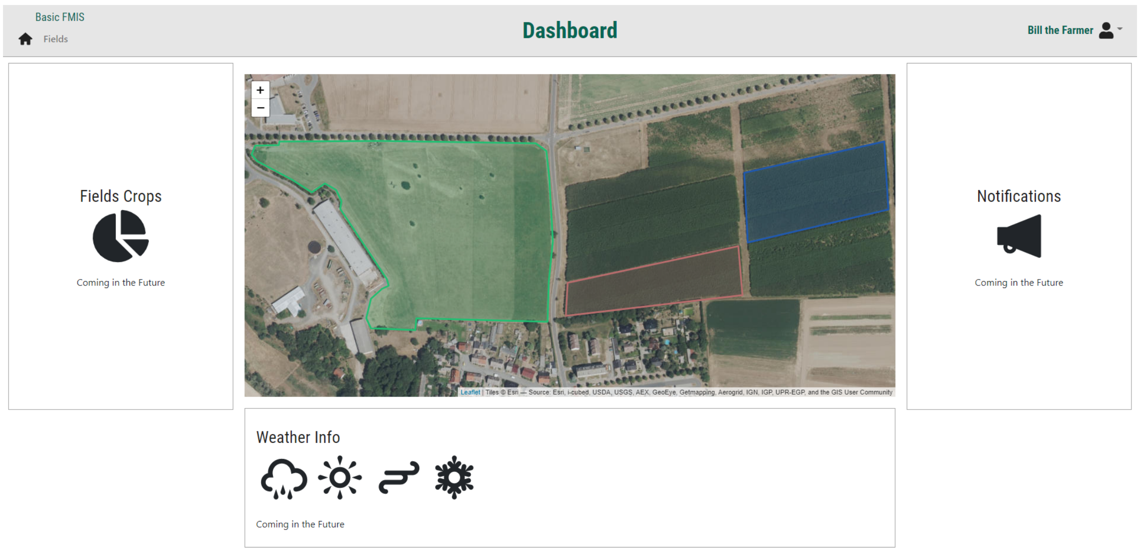
Figure 4.5 – Basic FMIS Login



Source: The Author

clicking on the *New Field* button in the top right corner. The *Fields List Page* is shown in Figure 4.7. The *New Field* button shows a modal to the user to fill the new field's name and after confirming it, if the creation request to the ADS Platform was successful, the application redirects to the new field's management page for further updates.

Figure 4.6 – Basic FMIS Dashboard



Source: The Author

The *Field Management Page* is specific to visualize the selected field information and boundaries on the map. By clicking on the *Field Administration* button in the top right corner of the page, the user can navigate to the *Field Administration Page* and by

Figure 4.7 – Basic FMIS Fields List

Source: The Author

clicking on the *Work Records* button, they can navigate to the *Fields Work Records Page*. The *Field Management Page* is shown in Figure 4.8.

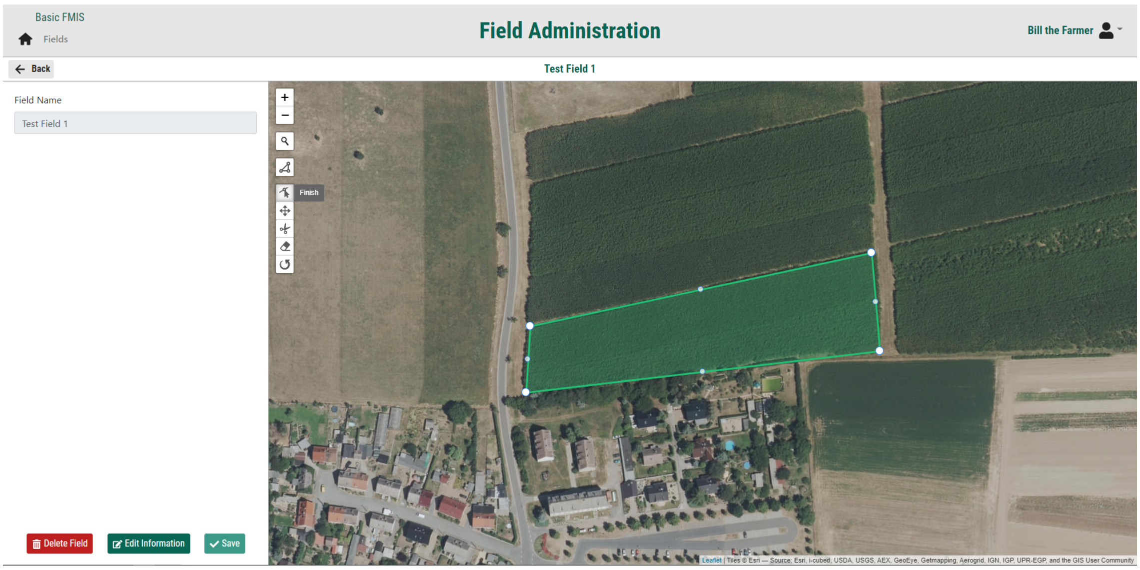
In the *Field Administration Page*, the user can update the field's information by clicking in the *Edit Information* button which toggles the form to be editable, and the button changes its color to a lighter green and its text to "save" for the user to submit the new data to the Field Twin. Basic FMIS performs a pre-verification of the input data and displays feedback next to the form field for the user to change it if needed. If the input is correct and the submission request is successful, Basic FMIS displays a confirmation toast in green, otherwise an error toast in red is displayed. By clicking the *Edit Boundaries* button, the user can edit the field boundaries through the map. The map functionalities include: rearrange the current polygon, cut the polygon, add a new polygon, delete the polygon and create a new one and browse the map by searching an address. Furthermore, they can delete the Field Twin, which triggers a modal to confirm the decision and, if confirmed and accepted by the ADS Platform, redirects the application back to the *Dashboard*. The *Field Administration page* in edit boundaries mode can be seen in Figure 4.9.

The *Field Work Records Page* presents all farm work logs stored in the Field Twin in a list design. The work records can be filtered by operation type and when clicked, their information is displayed in a read only form to the right. This page is depicted in Figure 4.10.

Figure 4.8 – Basic FMIS Field Management

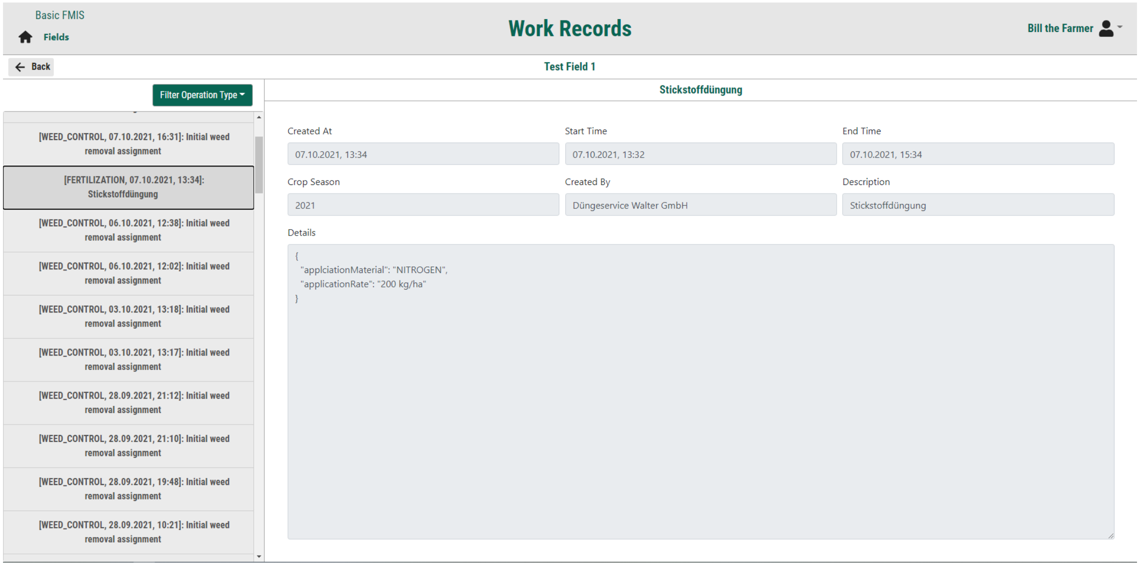
Source: The Author

Figure 4.9 – Basic FMIS Field Administration



Source: The Author

Figure 4.10 – Basic FMIS Field Work Records



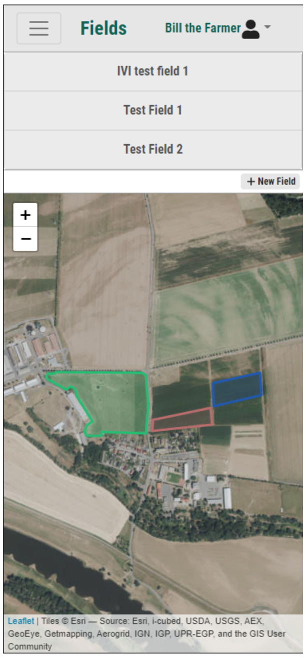
Source: The Author

In addition, Basic FMIS as a whole is mobile compatible and can be completely used from a smartphone. Some of the most important pages in their mobile design are presented in Figures 4.11, 4.12 and 4.13.

4.4 Chapter Summary

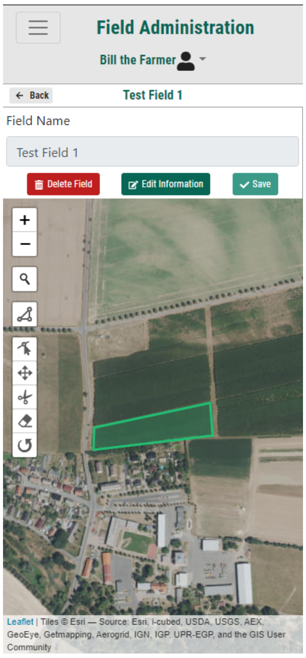
In this chapter, the development of the Basic FMIS prototype was described. Its motivation is based on its total compatibility with the ADS Platform and other COGNAC services also in development. It was designed as a Single-Page Application, in order to get a faster rendering and the benefit to provide a mobile version with less effort. Also, the main technologies chosen were JavaScript language and React library for the front-end development. Basic FMIS's main functions are to view and manage the Field Twin basic data as name and boundaries. It can also display the work records of tasks performed in the field by other projects inside COGNAC. The use case diagram and sequence diagrams depicting these use cases were shown to explain these functions in more detail. Finally, Basic FMIS was demonstrated with its main pages and features in figures.

Figure 4.11 – Basic FMIS Mobile Fields List



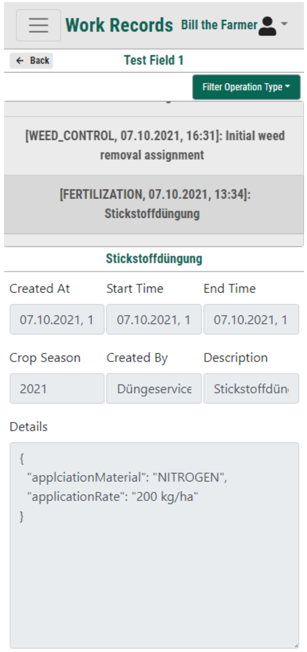
Source: The Author

Figure 4.12 – Basic FMIS Mobile Field Administration



Source: The Author

Figure 4.13 – Basic FMIS Mobile Field Work Records



Source: The Author

5 CONCLUSION

In this work, the COGNAC project's proposal of the integration of DTs in the agriculture domain through the ADS Platform, in search for a great interoperability between the systems and ecosystems that may connect to it, was demonstrated and validated in the context of a sugar beet farming use case. The use case of sugar beet farming was created according to the common way this process is done in Germany. Three steps from the BPM Lifecycle presented by Dumas et al. (2018) - Process Discovery, Process Analysis, and Process Redesign - were utilized to accomplish it. The current process was discovered and semantically validated in an interview-based method with a domain expert, generating the as-is process model in BPMN along with the process text description. Subsequently, the as-is model was analyzed following the Waste Analysis methodology, resulting in an Issue Register table to be used in the redesign step. Based on the Issue Register table and the as-is model, the process was redesigned according to the Lean methodology, generating the to-be process model including the ADS Platform DT concept. Furthermore, a FMIS prototype, the Basic FMIS, was developed to be a part of the validation of the to-be process by representing a system that can fully depend entirely on the DT data.

The study of the sugar beet farming process as it is commonly performed today with the use of the BPM lifecycle steps methodologies, emphasizes the need for more interoperability, security and quality in the agriculture data space, which includes systems, services and digital ecosystems used by the farmers. This was observed through the process analysis step, where issues already pointed out by farmers were identified and, therefore, confirmed. Furthermore, the enhanced process obtained from the redesign step shows a reduction on the number of tasks needed to be performed by the farmer and an improvement on the process data quality and interoperability through the enforcement of data format standards and the centralization of data in the field twin. Hence, corroborating with the importance of COGNAC's proposed concept. Therefore, this work has accomplished its goal of contributing to the project's concept validation. Furthermore, another contribution of this work was the development of a FMIS prototype capable of connecting to the ADS Platform and the DT on it to demonstrate the DT data usage and that a system can rely completely on it as well.

In regard to limitations of this work, a quantitative analysis and validation of the sugar beet process models was not done since the task's duration could not be defined as it diverges from farm to farm, so it could be only deducted that the process efficiency and data quality was improved. Limitations of the prototype are that there are still a variety of functionalities that can be implemented on it for it to truly become useful for a real farmer and be available for any ADS Platform user.

Future work comprises applying the BPM steps onto other use cases relevant to the agriculture domain, so they can be further analyzed and improved accordingly to evaluate if the COGNAC's proposed concepts also fit these use cases' needs. Additionally, the Basic FMIS can be further updated to provide more functionalities related to crop farming and the Field Twin with the intent to become a fully realized FMIS that can live in the ADS and be available for farmers to use. Another interesting lane to be taken is, after the release of the Basic FMIS, to use process mining on the application's execution logs to model the application's as-is process. After that, a compliance analysis can be performed against the to-be model of the sugar beet farming created in this work to validate the conformity of the Basic FMIS with the proposed process.

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