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Reference Model as Support for the Implementation of Agriculture 4.0

Jaqueline IAKSCH[a,1], Juliane CAMATTI [a], Milton BORSATO [a] and Maurício INFANTINI[b]
[a] *Universidade Tecnológica Federal do Paraná (UTFPR), Brazil*
[b] *CNH Industrial, Brazil*

Abstract. Agriculture is facing increasing challenges due to several factors such as population growth, climate change, and variation of prices practiced by the market. It has been looking for ways to improve profitability and agricultural efficiency through better management control based on information and knowledge generated on the farm in its specific context. Innovative technologies and solutions have been applied as an alternative for the collection and processing of this information with the fourth industrial revolution, which is generated by systems, equipment, markets, and agents involved in agricultural production. Transforming this data collected in the field into valuable data that supports better decision-making is essential. Through a literature review, it was established that the artifact to be developed in this project corresponds to an information model over an agricultural scenario. Following the Design Science Research (DSR) methodology, to reach this objective will be necessary to develop three artifacts. In this article, the first artifact is presented: a model that provides a systemic view and characterizes Agriculture 4.0.

Keywords. Agriculture 4.0, Farm 4.0, Reference Model, Transdisciplinary Engineering

Introduction

Technological advances have been driving drastic changes in industries since industrial revolutions started [1].Thus, several technologies are available for Industry 4.0 to achieve its objective related to continuous improvement, greater efficiency, safety, and operations productivity [1], [2].

As in industry, the agricultural sector is being transformed with the use of these new technologies. From Industry 4.0, Agriculture 4.0 appeared, offering new opportunities through the availability of interconnected and intensive technologies, which arise from Industry 4.0 [3].

Agriculture is considered highly unpredictable due to the high dependence on weather and environmental conditions (i.e., rainfall, temperature, humidity), uncertain events (i.e., animal diseases, pests), and market price volatility. For this reason, there is a great need to use technologies and data analysis to help farmers about the conditions and risks of their farms, enabling them to take appropriate and timely measures to protect their crops [4].

[1] Corresponding Author, Mail: jaquelineiaksch@alunos.utfpr.edu.br.

With the advent of intelligent machines and sensors, the amount and types of data have grown dramatically. Thus, these data are increasingly guiding agricultural processes [5]. Technological solutions (i.e., Bluetooth, Global Positioning System - GPS, Radio Frequency Identification - RFID) combined with communication between operators and agricultural machines at all levels of collaboration make it feasible to create a self-optimizing structure [6]. According to [7], current sensors provide very accurate data, and the actuators are capable of managing irrigation, changing weather conditions, or even enrich the soil with the necessary nutrients.

Thus, farmers are interested in business models that support revenue generation from data captured through IoT technologies [8]. From the data collected and generated by various devices and communication technologies, it is possible to build knowledge bases that store complex and unstructured information. However, a model with information in an organized and complete way, that provides relevant knowledge, can be used universally and implements smart agriculture is still a challenge [9], [10].

According to [11] it is possible to perceive the inexistence of works focused on the agricultural area that consider creating a model that characterizes Agriculture 4.0. It is also possible to notice the absence of a model that depicts, in an integrated and universal way, all the farm-oriented agents to Agriculture 4.0, with all technologies and relations between them. Besides, was identified the need to create an information model across a generic agricultural scenario enabling data analysis and event prediction to anticipate decision making.

In this context, this article presents the first artifact of extensive research, in partnership with a company that produces agricultural equipment, which aims to develop an information model across a generic agricultural scenario, capable of selecting and interpreting agricultural implements sensors data. The objective of this paper is to propose an Agriculture 4.0 reference model through the adaptation of The Reference Architectural Model Industry 4.0 (RAMI 4.0).

This article is structured in four sections. Section 1 presents a theoretical foundation necessary for the understanding of the research. The following section describes the methodological aspects considered. In Section 3 the development of the proposed reference model is presented. Section 4 presents the final considerations and conclusions about the work and suggests recommendations for future work.

1. Theoretical Background

1.1 Industry 4.0

Source [12] considers Industry 4.0 a manufacturing revolution that presents a new perspective for the industry combining new technologies to obtain maximum performance with minimum use of resources. This movement has led companies to rethink how they manage their businesses and processes, allowing for real-time production planning and control [13].

To implement Industry 4.0, vertical and horizontal integrations of all its principal functions are necessary, giving rise to a new way for companies to position themselves in the value chain and manage their production. This integration, combined with the emergence of new technologies, allows productive systems to be more efficient since they are more responsive and predictive. Thus, Industry 4.0 is not just a digitization movement but a combination of diverse technologies based on innovation [2].

Several reference models represent industry 4.0, such as The Industrial Internet Reference Architecture (IIRA), The Stuttgart IT - Architecture for Manufacturing (SITAM), The Reference Architectural Model Industry 4.0 (RAMI 4.0), among others.Reference models are sets of interconnected and clearly defined concepts developed by specialists to understand the interactions between entities in an environment [14].

Between the existing architecture reference models for industry 4.0, the most known and used is RAMI 4.0 [15]. Illustrated in Figure 1, this model, developed in Germany [16], is an adaptation and expansion of the Smart Grid Architecture Model (SGAM) to meet requirements 4.0 [14].

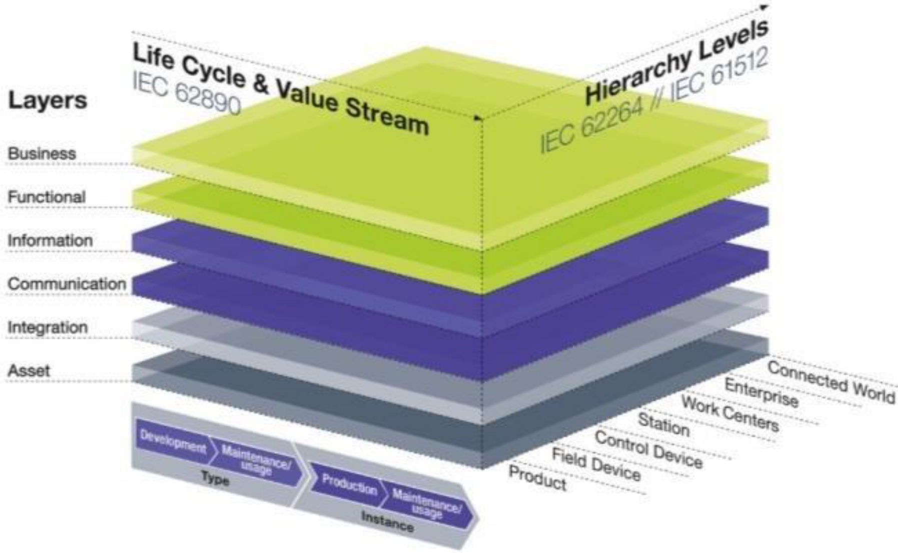

Figure 1. RAMI 4.0 [24]

RAMI 4.0 aims to group and represent different aspects of the industry in a unique model, describing the most important aspects of intelligent production systems with an architectural view of Industry 4.0[15], [17], [18]. According to [14], this model provides a reference for a basic 4.0 architecture system, serving as a basis for analyzing its relationships and details.

RAMI 4.0 is a three-dimensional model developed based on horizontal and vertical integration and end-to-end engineering. The horizontal axis (at the right of Figure 1) represents the hierarchy levels, i.e., the layers of integration of a business control system (enterprise, work centers, station, and control device) and three other layers to support the smart concept. The Field Device layer allows controlling equipment and systems in an intelligent way (use of sensors). The Product layer represents the interdependence between the products to be manufactured and the production equipment. The Connected World layer, on the other hand, allows the representation of the expansion of factory limits, with the institution of partnerships and collaborative networks [14], [17], [19].

The left horizontal axis - Life Cycle and Value Stream - shows the production cycle and the product life cycle [17]. Finally, the vertical axis (Layers) represents the hierarchical layers for information, decomposing and representing perspectives (i.e., data

maps, behaviors) of physical entities. Thus it defines the structure of information and communication technologies for industry 4.0 [14], [17].
Thus, RAMI 4.0 integrates vertically and horizontally concepts, end-to-end engineering, and life cycle [19]. Also, the model allows the division of processes into packages, facilitating communication and data processing. This model subdivides a complex system with internal connections into smaller and easier to deal with subsystems [15].

The combination of technologies results in the development of intelligent factories that use resources in a highly efficient way and can adapt quickly to different market scenarios [12]. In this context, the changes and technologies present in Industry 4.0 influence the way companies in the agricultural sector walk in the market. same sense. Thus, with great potential for growth and productivity, the agricultural sector has been adopting and adapting these same technologies, giving rise to the so-called Agriculture 4.0 [20].

1.2 Agriculture 4.0

Currently, Agriculture 4.0, as well as Industry 4.0, has all processes connected to the cloud. Thus, Agriculture 4.0, also called smart agriculture or digital agriculture, is defined as Industry 4.0 of the primary sector [3], [6], [21], [22].

The development of technologies such as systems and data transmission has led to radical changes in the agricultural work environment in recent years. These changes updated systems information, markets, and agents involved in the production, so it is necessary to provide information for decision-making related to production and strategic and managerial issues [23]. Figure 2 presents the progress made in agriculture resulting from the leading industrial revolutions.

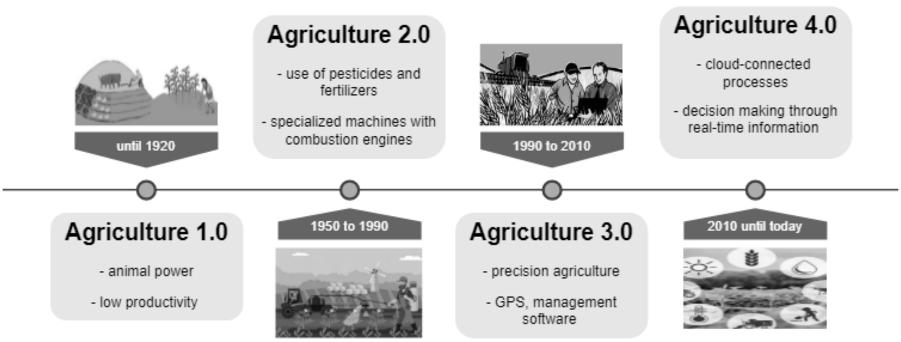

Figure 2. Agricultural progress

Although smart farming and precision farming are often indistinguishable treated, they are thoroughly different [24]. Precision agriculture allowed intelligent agriculture emergence. Intelligent agriculture uses the collection, processing, and analysis of data in real-time, automating agricultural procedures. Thus, allowing the improvement of operations, management, and decision making [4].

Unlike precision agriculture, which takes into account only the variability of the field, intelligent agriculture goes further, including the entire agricultural production cycle, aiming to improve context and situation awareness triggered by real-time events [25]. Combining digital agriculture and precision farming technologies will be possible to reduce costs and maximize yields and profits [24].

According to [26], digital agriculture has relevant information to deal with challenges related to climate change, such as water scarcity, and environmental problems, which make food production more difficult and expensive. Decision-making and agricultural planning can be further supported, leading to more effective and efficient agriculture [27].

Agriculture 4.0 means the use of technologies to increase profitability and sustainability in agriculture [28]. Companies that supply agricultural products have sought to offer alternatives to collect and process information [29]. Machines are equipped with sensors that measure data in their environment and evaluate the machine's behavior. Thus, big data technologies play an essential role in this development [5], [30].

[5] state that digital agriculture has been driven by the rapid development of cloud computing and the internet of things, using information and communication technology in the cyber-physical management of farms. It can also be said that Agriculture 4.0 is the application of technology systems with big data and precision in agriculture [26], [28].

Digital agriculture provides several improvements as the increase of harvest efficiency, risks minimizing, costs reducing and profitability increasing, and improving decision-making management [27]. The application of modern information and communication technologies (ICT) increases the production and financial return and reduces the environmental impact in the agricultural sector. [31]. According to [27] The use of technologies such as cloud computing, remote sensing, the internet of things, data-driven agriculture, and Big data analysis is the basis of Smart agriculture.

2 Methodological Aspects

The present research is based on the Design Science Research (DSR) approach. DSR aims to improve the perception of professionals in their fields so problems can be solved [32], [33]. Thus, this approach assists in the development of artifacts that attempt to solve observed problems, make research contributions, evaluate solutions and communicate results [33]. Artifacts are designed in order to change something in a system, aiming to solve problems or improve performance, are defined as methods, models, constructions, and instantiations [34].

According to [35], the development and application of an artifact acquire knowledge and understanding of a problem and its solution. Thus, this research presents a model as the artifact to be designed. Models are sets of propositions or statements that describe and represent a real scenario [34].

The DSR approach defines six steps that must be followed to create a consolidated artifact. These steps are: (*i*) problem definition and motivation; (*ii*) definition of the Solution objectives; (*iii*) Design and development; (*iv*) Demonstration; (*v*) Evaluation; and (*vi*) Communication. Figure 3 presents a flowchart with these phases.

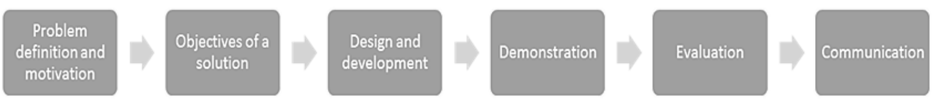

Figure 3. DSR steps. Adapted from [28].

This article will present only three steps of the DSR approach. The other phases are yet to be performed in future research.

Phase 1 - Problem identification and motivation: The first step of the DSR is related to the identification of an application context of the solution. The main objective at this stage is to direct the researcher to solve an existing problem.

Phase 2 - Definition of the Solution objectives: In this second step of the DSR the objectives expected to solve the problem.

Phase 3 - Solution design and development: This stage is correlated to the construction of the artifact. Therefore, this phase includes the development of three models that integrate and form the complete artifact.

3 Results and Discussion

This section presents the results obtained in this research, which follow the steps of DSR described in methodological aspects, giving the deliverables obtained in the first three steps of this approach.

3.1 Problem Identification and Motivation

At this step, meetings with members of this project's partner company were carried out. In the context of an intelligent farm, the integration levels of the technologies adopted by the company in their products were identified. Besides, a literature review about the research topic was performed, to obtain a conceptual basis on the subject, assist in identifying research already carried out and its results achieved, detecting trends and research gaps on the topic in question.

Based on that previous study carried out by the authors [11], [36], it was accomplished that researches related to Agriculture 4.0 do not present a systemic view, deal with the subject in a restricted way, seeking to find isolated solutions. Also, companies that provide agricultural equipment are equipping their products with sensors that can collect various types of data, but these data are not used to generate information useful, either to improve the overall productivity of the farms [11], [36].

3.2 Definition of the Solution objectives

The objectives to solve the problem are expected in this second step of the DSR. Thus, after conducting the literature review, it was established that the artifact to be developed in this project corresponds to an information model over an agricultural scenario

The model must capture data related to maintenance in existing databases and powered by IoT, making possible the objective of controlling and predicting the need for equipment maintenance can be achieved, assisting predictive decision making.

Product and maintenance engineers predict and schedule the maintenance of agricultural equipment taking into account scenarios that approximate their real working conditions in the field. However, equipment is used in regions with very different climates, which have particularities related to the ambient temperature and humidity that often make this maintenance schedule a failure.

To predict the need for maintenance, and as a consequence, to increase the availability of equipment, the artifact to be developed will focus on data captured by sensors present in equipment, which can be related to component failure. Thus, enabling predict the need for maintenance and consequently promote an increase in equipment availability.

3.3 Solution design and development

To achieve the objective defined in the second step of the DSR will be necessary to develop three artifacts. In this article, the first one is presented, the other two are still being developed.

So the first artifact is presented in this article. It was created as an initial phase to support the construction of the other artifacts, as well as the development of the information model, which is the main objective of this project.

Thus, the first artifact was created: a model that provides a systemic view and characterizes Agriculture 4.0.

This reference model of Agriculture 4.0 was proposed based on an Industry 4.0 model already existing in the literature, the RAMI 4.0, incorporating its principles and adapting them to the agricultural reality. As can be seen in Figure 4, the proposed model considers three dimensions.

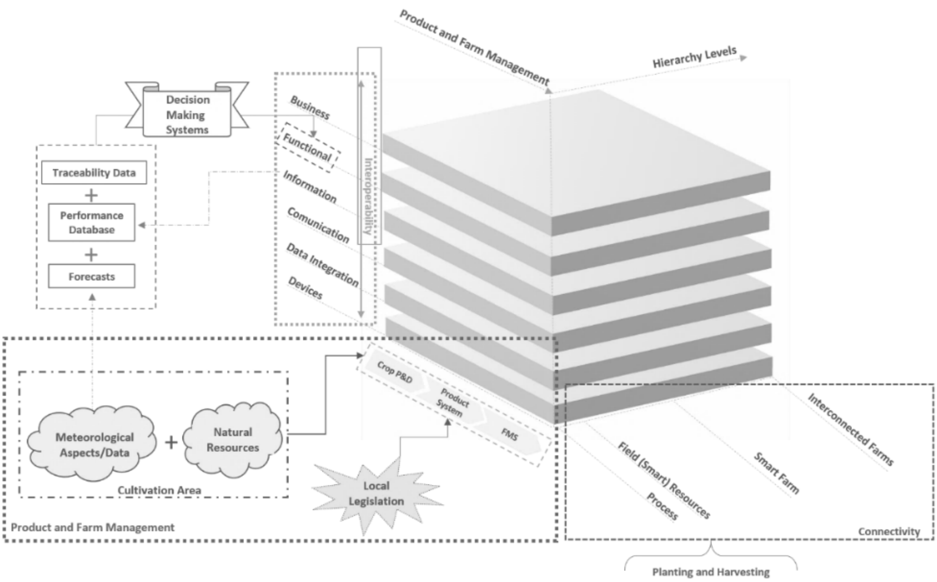

Figure 4. Reference Model for Agriculture 4.0

The horizontal axes represent the hierarchical levels and the agricultural production cycle. On the right horizontal axis of the reference model, all processes involved in agriculture are considered, from planting to harvest, emphasizing the concept of connectivity. Thus, this axis represents the processes and equipment data collection through the relationship between equipment and intelligent systems (i.e., sensors).

The smart farm concepts are also represented in this dimension, considering all the equipment and systems interconnected. Finally, the Interconnected Farms layer, which is related to RAMI 4.0 Connected World layer, aims to represent the expansion of farm limits, with partnerships institution and collaborative farms network.

On the left horizontal axis of the model - Product and Farm Management - the development and production of plantations and management systems are presented. The cultivation place legislation must be considered in the agricultural production system and was highlighted in the model. Two other important aspects were considered: meteorological data of the cultivation region and its natural resources. Meteorological data (i.e., precipitation and temperature) and natural resources data (i.e., soil type and pests) must be combined to support the decision to choose the crop and its production.

As RAMI 4.0 model, the vertical axis represents the hierarchical layers for information. However, the proposed model highlights the interoperability between them In this axis, it is possible to identify the representation of support systems for decision-making, depending on data traceability and equipment performance, and forecasts derived from meteorological databases. Thus, Functional and Information hierarchical layers are highlighted in the model.

Figure 5 presents a preview of the model that is being transcribed in SysML language in the Enterprise Architect software, which is still in the development phase.

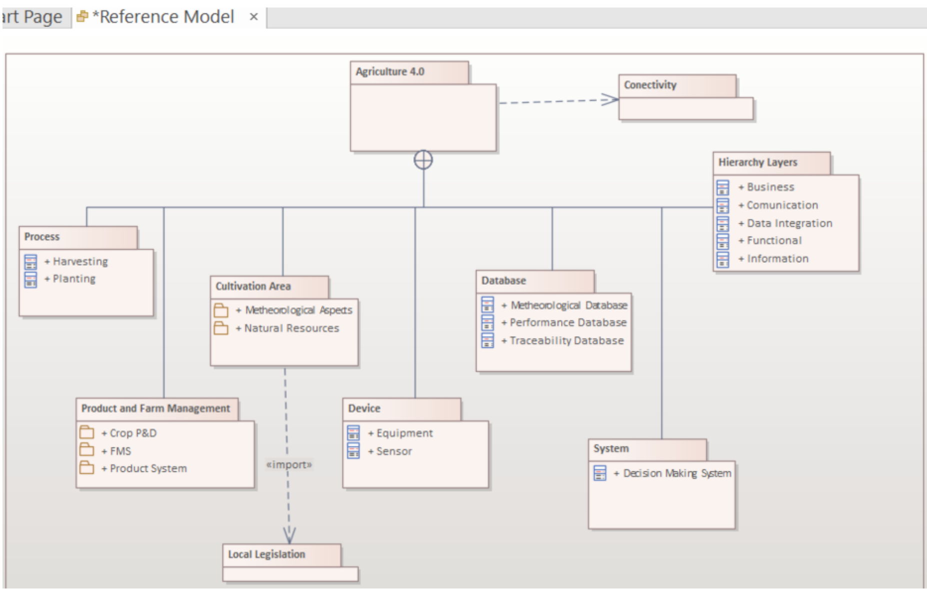

Figure 5 - Agriculture 4.0 - Reference Model

4 Conclusions and Future work

The reference model for Agriculture 4.0 proposed was developed considering the particularities linked to the agricultural scenario. It provides a view and describes the most important aspects of smart agriculture production systems. Thus, the reference model developed in this work allows the direction of a generic vision of Agriculture 4.0 and will serve as a basis for the development of the other steps to achieve the general objective of the research.

Hence, after the reference model creation, as future work, a model that depicts all the agents of a farm-oriented to Agriculture 4.0 - Farm 4.0 will be developed, representing all technologies and relations between them in an integrated and universal way. Thus, it will be possible to operate a systemic view of the farm.

After modeling Farm 4.0, an information model over a generic agricultural scenario that enables data analysis and events prediction to anticipate decision making will be developed. This information model should capture the data generated in one of the information flows represented in the Farm 4.0 model to control and predict the need for equipment maintenance, assisting decision making in a predictive manner. Enterprise Architecture software and cloud computing will be used to make it possible to elaborate the model by structuring layers of information.

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